Sub no – 304
Iw no – 486

Molonglo Radio Observatory
1152 Hoskinstown Rd
via Bungendore
NSW 2621
10/12/2001

Productivity Commission Enquiry
Radio Communications

Enclosed is my submission to the enquiry into Radio Communications on spectrum issues that have affected observatory operations.

Yours faithfully

D. Campbell-Wilson

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Review of the Radio Communications Acts
and the
Role Australian Communications Authority

Molonglo Radio Observatory is a non commercial user of the radio spectrum. The Observatory mission is to image the faint radio emissions from the universe. Some emissions are 10 billion years old and very weak. The signals are weak in the extreme. The observatory fills a unique niche in world and southern hemisphere radio astronomy. When not in maintenance we operate 24 hours per day using a small fraction of the radio spectrum - a 4 MHz bandwidth centred on 843 MHz.

The observatory is unique, in that it enjoys protection in legislation and operates outside the ITU radio astronomy bands. The protection and coordination requirements are defined in the Radio Communications ACT 1992 (Appendix 1).

The observatory is a licensed fixed receiving site. The license is maintained to alert other users to our existence and our passive use of the radio spectrum. It is our experience this is necessary as the footnote AUS 63 is inadequate and an unsuccessful means of alerting other spectrum user to our presence and coordination requirements.

A considerable investment has been made by the Australian Communications Agency (ACA) and the observatory to quantify reasonable protection and the coordination requirements. The technical assessment is reported in both appendices 1 and 2.

The Observatory's Operational Experience:

The coordination requirements and protection do not translate into reality prior to new telecommunications system introduction.

Protection recognition happens after the fact, post incident.

It is my experience in multiple cases that a new communications system will be installed and the first the observatory will know of the new spectrum usage is observations and data being corrupted.

The effort and time required to track down, identify and mittigate the interfering system is considerable.

In one case the "Bulls Head incident" eight months of data was damaged. Some beyond use but all data showed degradation.

The interfering source, an incorrectly installed Telstra link was eventually identified and a partial remedy effected (Appendix 3). The issuing of the spectrum licences without coordination, the installation without coordination and the technical failure to verify the system performance as per the frequency assignment are major issues that should be addressed by both the spectrum user and spectrum managers.

The "Burra Incident" was short lived but is the clearest failure of coordination (Appendix 4).

The failure in coordination defeats the intent of the ACT with respect to providing protection to the observatory.

Coordination and Communication between users:

Enhancements to the present administrative procedure.

Automatic flagging of site protection on the ACA web site and data base if a system is within double the coordination distance and is within the frequency range specified by the protection.

The notification distance doubling is to alert users and also to allow for terrain modelling errors in propagation calculations.

Mandatory written notification to existing spectrum users of new systems using the same portion of the radio spectrum within the coordination region.

Equipment testing and system introduction and withdrawal with times and dates to be posted on the ACA data base with notification to parties within the coordination region and frequency range.

Nomination of contact officers to facilitate coordination between spectrum users. These to be posted on the ACA web site to enable initial contact and coordination.

DCW

Appendix 1

Commonwealth of Australia

Radiocommunications Act 1992

Radiocommunications Advisory Guidelines (Protection of Molonglo Observatory Synthesis Telescope) 1998

THE AUSTRALIAN COMMUNICATIONS AUTHORITY makes the following guidelines under subsection 262 of the *Radiocommunications Act 1992*

Dated 4 February 1998.

AUSTRALIAN COMMUNICATIONS AUTHORITY Common Seal ACA

A J Shaw
Chairman

R Horton
Deputy Chairman

Australian Communications Authority

BACKGROUND
The Molonglo Observatory Synthesis Telescope ('MOST') is a radio telescope located approximately 30 km to the East of Canberra that monitors radio signals from weak celestial radio sources in a frequency band centred on 843 MHz. The frequency band 825-845 MHz is subject to spectrum licensing and all transmitters to be operated in this band may potentially affect the MOST. These advisory guidelines set out the compatibility requirement that would provide the MOST with a reasonable level of interference protection from transmitters operating in this band. A suggested approach to assessing the compatibility is also provided. Spectrum licences in the relevant bands will require that operation of transmitters under the licence must not interfere with the MOST. This requirement to protect the MOST will cease at the end of 2008.

PART 1—GENERAL INFORMATION

Title

1.1 These guidelines are called the Radiocommunications Advisory Guidelines (Protection of Molonglo Observatory Synthesis Telescope) 1998.

Commencement

1.2 These guidelines commence on 4 February 1998.

Interpretation

1.3 In these guidelines:

"compatibility requirement" means the requirement set out in Part 2;

"coordination threshold distance" means the maximum distance from the MOST receiver within which a transmitter operated under spectrum licence needs to be coordinated;

"EIRP" means equivalent isotropically radiated power;

"the MOST" means the radio telescope operated by the University of Sydney located about 30 km east of Canberra, ACT at latitude 35° 22' 30" S, longitude 149° 25' 35" E. The telescope has a receive frequency of 843 MHz with a 3 dB bandwidth of +/- 1.5 MHz. *[Note: Australian Map Grid coordinates - Zone: 55, Easting: 720420, Northing: 6082653.]*.

Purpose of these guidelines

1.4 The purpose of these advisory guidelines is to set out the compatibility requirement and provide a basis upon which spectrum licensees in the 825-845 MHz band may coordinate the operation of their transmitters so as to prevent interference being caused to the MOST. If such interference is caused to the MOST the ACA will have regard to whether or not the spectrum licensee has coordinated the transmitters in a manner that meets the compatibility requirement set out in these guidelines, during interference settlement.

1.5 The compatibility requirement is intended to reflect the ACA's policy of providing adequate interference protection to the MOST. This does not alter the fact that the ACA will deal with each interference scenario on a case by case basis according to its own circumstances.

1.6 The compatibility requirement set out in these guidelines is based on the results of tests[1] conducted to determine the interference susceptibility of the MOST. These tests were undertaken jointly by the Spectrum Management Agency, the Department of Communications and the Arts and the University of Sydney. The compatibility requirement and the methodology presented in these guidelines have been developed in consultation with industry. Spectrum licensees should take all reasonable steps to ensure that, whatever coordination methods are used, the compatibility requirement set out in these guidelines is met in respect of any transmitters to be operated under a spectrum licence.

1.7 The compatibility requirements for the MOST are set out in Part 2.

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[1] Reference: Spectrum Planning Report SPP 5/96, "Interference Susceptibility of the Molonglo Observatory Synthesis Telescope.

PART 2—COMPATIBILITY REQUIREMENT

2.1 The compatibility requirement for spectrum licensees to protect the MOST is as follows:

$$Ptx - L = Prx$$
$$Prx = Prx_0 - G(\phi) - G(f)$$

where:

Ptx is the EIRP of the proposed transmitter in the direction of the MOST (dBm);
L is the transmission loss (dB) (definition ref: ITU-R Rec. P.341-4);
$G(\phi)$ is the relative gain of the MOST as a function of the bearing to the transmitter (dB) found from Table 2;
G(f) is the relative gain of the MOST as a function of frequency (dB) found from Table 3;
Prx is the received power at the MOST; and
Prx_0 (the worst-case protection level) = -174 dBm.

2.2 The average power received by the MOST within its 3 dB bandwidth (3 MHz) should not exceed the compatibility requirement for more than 10 % of the time as a result of variations in propagation conditions (ref: ITU-R Rec. RA.1031-1).

2.3 The coordination methodology set out in Parts 3 to 6 inclusive may be used to determine whether a transmitter proposed for operation under a spectrum licence ('the proposed transmitter') will meet the compatibility requirement.

PART 3—FINDING OUT IF DETAILED COORDINATION IS NECESSARY

Distance to the MOST

3.1 Calculate the distance between the proposed transmitter and the MOST.

3.2 If the proposed transmitter is within 10 km of the MOST and is intended to operate within the frequency range 825-845 MHz the spectrum licensee should not operate the transmitter unless steps are taken as set out in Part 6.

3.3 If the proposed transmitter is more than 10 km from the MOST and is intended to operate in the frequency range 825-845 MHz, the procedure described in clauses 3.4 to 3.11 inclusive may be used to determine if the compatibility requirement can be met. For mobile transmitters intended to operate in the frequency range 825-840 MHz, and exempt from device registration as provided for in the spectrum licence, the compatibility requirement does not apply.

Coordination threshold distance

3.4 Table 1[2] may be used to evaluate whether a detailed coordination assessment is necessary by determining the 'coordination threshold distance' for a proposed transmitter.

3.5 Before using Table 1, spectrum licensees should take note of the underlying principles used in developing the table as set out in clauses 4.1 to 4.2 and make a judgement as to whether these assumptions are appropriate for their proposed transmitter(s). If the assumptions are not appropriate, or the range of values of effective antenna height or EIRP is

[2] Note that due to the range of EIRP values shown in the table, the table spans two pages. These two pages can be joined horizontally to form one complete table.

not sufficient, then Table 1 should not be used and a detailed coordination assessment will be necessary as described in Part 5.

3.6 The methodology for using Table 1 to find the coordination threshold distance is set out in Part 4. Determining the coordination threshold distance from Table 1 is a two stage process. The first stage determines an initial distance and the second stage refines the required protection level, thereby allowing a reduced distance to be determined from the table in many cases. The second stage is unnecessary if the distance between the proposed transmitter and the MOST is greater than the initial distance determined from the table.

3.7 The initial coordination threshold distance should be found from Table 1 as described in clause 4.3.

3.8 If the proposed transmitter is outside this coordination threshold distance then no coordination with the MOST is required and the transmitter may be operated (providing other relevant conditions of the spectrum licence are met).

3.9 If the proposed transmitter is closer to the MOST than the initial coordination threshold distance then the coordination threshold distance should be refined, if possible, as described in clauses 4.4 to 4.6.

3.10 If the proposed transmitter is closer to the MOST than the revised coordination threshold distance then the spectrum licensee should conduct a detailed coordination assessment as set out in Part 5.

3.11 If the proposed transmitter is outside the revised coordination threshold distance then no coordination with the MOST is required and the transmitter may be operated (providing other relevant conditions of the spectrum licence are met).

PART 4—USING THE COORDINATION THRESHOLD DISTANCE TABLE (TABLE 1)

Validity of Table 1 for the path between the proposed transmitter and the MOST

4.1 Table 1 was produced using the spherical Earth propagation model to calculate the coordination threshold distances listed in the table. Parameters used in the calculations included an effective Earth radius (k) of 5.5 and a receiver (the MOST) antenna height of 10 m. The transmitter antenna height used in each calculation was the effective antenna height listed in the same row of the table as the calculated distance.

4.2 Generally, the spherical Earth propagation model used in calculating the coordination threshold table will give less loss than the actual propagation path. However, care should be taken if the path is either unobstructed or obstructed by a single knife edge, as these propagation paths can result in less loss than the spherical Earth propagation model. In such cases the coordination threshold distance table should not be used.

Initial coordination threshold distance

4.3 Looking first at the upper part of Table 1 (upwards from and including the row titled "EIRP"): For a given EIRP and effective antenna height[3], a distance can be read from the table. This distance is the initial coordination threshold distance.

[3] The effective antenna height of the transmitting antenna may be determined with any valid methodology. The ITU-R defines the effective antenna height as the height of the transmitting antenna over the average level of the ground between distances of 3 and 15 km from the transmitter in the direction of the receiver (ref: ITU-R

Refining the coordination threshold distance

4.4 For a proposed transmitter closer to the MOST than the initial distance determined by using the upper part of Table 1, a further stage can be undertaken to determine whether the compatibility requirement can be reduced. By considering the directionality and frequency response of the MOST the compatibility requirement can be reduced thereby reducing the coordination threshold distance.

4.5 The total reduction in the compatibility requirement can be determined as follows:

(a) determine the bearing of the proposed transmitter from the MOST. Then look up the relative gain figure corresponding to this bearing in Table 2;

(b) using Table 3 find the frequency range relevant to the proposed transmitter's frequency bandwidth and then look up the corresponding frequency response figure;

(c) the total reduction in the compatibility requirement is the sum[4] of the two figures determined in sub clauses (a) and (b).

4.6 The left hand column in the lower part of Table 1 lists the amount by which the compatibility requirement has been reduced. Find the appropriate figure in the left hand column corresponding to the reduction in the compatibility requirement calculated in clause 4.5. If the appropriate figure is not listed, the next lowest figure should be used. (eg if the compatibility requirement is reduced by 29 dB, find 27 dB in the left column). The lowest value of EIRP that is equal to or greater than that of the proposed transmitter should then be located in the row corresponding to this reduction in the compatibility requirement. Once the appropriate EIRP is found in a particular column, this column can then be used in the upper part of the table to find the new coordination threshold distance for the appropriate effective antenna height.

PART 5— DETAILED COORDINATION ASSESSMENT

Detailed coordination

5.1 For a proposed transmitter to be sited closer to the MOST than the distance determined from the coordination threshold distance table, detailed coordination studies will be needed to determine if the transmitter can operate without interference to the MOST.

5.2 The methodology to be applied in conducting the detailed coordination has not been specified due to the range of possible system applications and potential interference scenarios. It is the responsibility of spectrum licensees to ensure that the studies are conducted with due care using supportable and valid methodologies such as those presented in ITU-R recommendations, ACA guidelines, or ACA radiocommunications assignment and licensing instructions (RALIs).

5.3 The objective in undertaking a detailed coordination study is to determine whether the signal level at the MOST from the proposed transmitter is below the level specified by the compatibility requirement. This level will range from -174 dBm to -104 dBm depending upon the proposed frequency and the bearing on which the signal

Rec. P.370-7). An alternative methodology developed by the ACA could also be used. This alternative method is used in spectrum licensing for evaluating the geographic device boundary for spectrum licensed transmitters.

[4] The absolute value of the sum should be used in Table 1.

arrives at the MOST. The appropriate compatibility requirement can be calculated by adding the reduction in the compatibility requirement determined in clause 4.4 to -174 dBm. The signal levels from proposed transmitters should not exceed this compatibility requirement for more than 10% of the time as a result of variations in propagation conditions. (ref: ITU-R Rec. RA.1031-1).

5.4 Detailed coordination studies can take into account the actual terrain between the MOST and the proposed transmitter(s). Knowing the nature of the terrain may allow a different propagation model to be used in calculating the propagation loss between the proposed transmitter and the MOST. If greater propagation loss results from using a different propagation model the coordination distances will be reduced. However, as noted in clause 4.2 some propagation paths may result in less loss than the spherical Earth propagation model that was used in calculating the coordination threshold distance table.

PART 6—COORDINATION OF TRANSMITTERS CLOSE TO THE MOST

6.1 Transmitters operating in the band 825-845 MHz and within 10 km of the MOST could cause interference by overloading the low noise amplifiers resulting in a blocking effect. The susceptibility of the MOST to this type of interference has not been characterised.

6.2 Spectrum licensees proposing to operate transmitters within this range should approach the Sydney University's Department of Astrophysics with a view to undertaking test transmissions to determine if such operation is feasible.

TABLE 1: Co-ordination Threshold Distances from the MOST

Effective Antenna Height (m)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)
	Stage 1: Determine initial distance from EIRP and effective antenna height.												
1200	271	285	290	229	313	318	327	341	347	355	369	375	383
600	193	207	212	170	234	240	248	262	268	276	290	296	304
300	139	152	158	130	180	185	193	207	213	221	235	240	249
150	101	114	120	101	141	146	154	168	173	182	195	201	209
75	74	87	92	81	113	118	126	139	145	153	166	172	180
37.5	54	66	71	65	92	97	105	118	123	131	144	150	158
10	27	38	42	44	61	66	73	86	91	99	112	117	125
3	10	17	21	28	37	41	48	60	65	72	85	90	97
1.5	*	*	11	19	24	28	35	46	50	57	70	74	82
	* Transmitters operating in any part of the 825-845 MHz band within 10 km of the MOST should undertake detailed coordination with the MOST.												
Prop Loss (dB)	144	149	151	154	159	161	164	169	171	174	179	181	184
EIRP (watts)	0.000001	0.000003	0.000005	0.00001	0.00003	0.00005	0.0001	0.0003	0.0005	0.001	0.003	0.005	0.01
Compatibility Requirement Reduced by (dB)	**Stage 2: Reduced compatibility requirement allows reduced distances for the same EIRP and effective antenna height. From the row below with the appropriate reduction in protection find the proposed EIRP and then read the new distance above from that column.**												
	EIRP (watts)												
3	0.000002	0.000006	0.00001	0.00002	0.00006	0.0001	0.0002	0.0006	0.001	0.002	0.006	0.01	0.02
6	0.000004	0.000012	0.00002	0.00004	0.00012	0.0002	0.0004	0.0012	0.002	0.004	0.012	0.02	0.04
9	0.000008	0.000024	0.00004	0.00008	0.00024	0.0004	0.0008	0.0024	0.004	0.008	0.024	0.04	0.08
12	0.000016	0.000048	0.00008	0.00016	0.00048	0.0008	0.0016	0.0048	0.008	0.016	0.048	0.08	0.16
15	0.000032	0.000095	0.00016	0.00032	0.00095	0.0016	0.0032	0.0095	0.016	0.032	0.095	0.16	0.32
18	0.000064	0.000190	0.00032	0.00064	0.00190	0.0032	0.0064	0.0190	0.032	0.064	0.190	0.32	0.64
21	0.000130	0.000380	0.00063	0.00130	0.00380	0.0063	0.0130	0.0380	0.063	0.130	0.380	0.63	1.30
24	0.000260	0.000760	0.00130	0.00260	0.00760	0.0130	0.0260	0.0760	0.130	0.260	0.760	1.30	2.60
27	0.000510	0.001600	0.00260	0.00510	0.01600	0.0260	0.0510	0.1600	0.260	0.510	1.600	2.60	5.10
30	0.001000	0.003000	0.00500	0.01000	0.03000	0.0500	0.1000	0.3000	0.500	1.000	3.000	5.00	10.00
33	0.002000	0.006000	0.01000	0.02000	0.06000	0.1000	0.2000	0.6000	1.000	2.000	6.000	10.00	20.00
36	0.004000	0.012000	0.02000	0.04000	0.12000	0.2000	0.4000	1.2000	2.000	4.000	12.000	20.00	40.00
39	0.008000	0.024000	0.04000	0.08000	0.24000	0.4000	0.8000	2.4000	4.000	8.000	24.000	40.00	80.00
42	0.016000	0.048000	0.08000	0.16000	0.48000	0.8000	1.6000	4.8000	8.000	16.000	48.000	80.00	159.00
45	0.032000	0.095000	0.16000	0.32000	0.95000	1.6000	3.2000	9.5000	16.000	32.000	95.000	159.00	317.00
48	0.064000	0.190000	0.32000	0.64000	1.90000	3.2000	6.4000	19.0000	32.000	64.000	190.000	316.00	631.00
51	0.130000	0.380000	0.63000	1.30000	3.80000	6.3000	13.0000	38.0000	63.000	126.000	378.000	630.00	1260.00
54	0.260000	0.760000	1.30000	2.60000	7.60000	13.0000	26.0000	76.0000	126.000	252.000	754.000	1260.00	2520.00
57	0.510000	1.600000	2.60000	5.10000	16.00000	26.0000	51.0000	151.0000	251.000	502.000	1510.000	2510.00	5020.00
60	1.000000	3.000000	5.00000	10.00000	30.00000	50.0000	100.0000	300.0000	500.000	1000.000	3000.000	5000.00	10000.00
63	2.000000	6.000000	10.00000	20.00000	60.00000	100.0000	200.0000	599.0000	998.000	2000.000	5990.000	9980.00	20000.00
66	4.000000	12.000000	20.00000	40.00000	120.00000	200.0000	399.0000	1200.0000	2000.000	3990.000	12000.000	20000.00	39900.00
70	10.000000	30.000000	50.00000	100.00000	300.00000	500.0000	1000.0000	3000.0000	5000.000	10000.000	30100.000	50000.00	100000.00

Notes:
1. Calculated distances are based on the spherical Earth diffraction loss model (loss not exceeded for 10 % of the time).
2. Protected receive level Prx=-174 dBm.
3. If a value of EIRP, effective antenna height or protection reduction is not listed then the next highest value should be used. Alternatively, the results obtained from using both the higher and lower values could be interpolated

TABLE 1: Co-ordination Threshold Distances from the MOST (continued)

Effective Antenna Height (m)	Stage 1: Determine initial distance from EIRP and effective antenna height. Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Distance (km)
1200	397	403	412	426	432	440	454	460	469	483	489	497
600	318	324	332	346	352	361	375	380	389	403	409	417
300	263	268	277	291	298	305	319	324	333	347	352	361
150	223	228	237	251	256	265	279	284	293	307	312	321
75	194	199	207	221	227	235	249	254	263	277	282	291
37.5	171	177	185	199	204	213	226	232	240	254	260	268
10	138	144	152	165	171	179	193	198	207	220	226	234
3	111	116	124	137	142	151	164	169	178	191	197	205
1.5	95	100	108	121	126	134	148	153	161	175	180	189
Prop Loss (dB)	189	191	194	199	201	204	209	211	214	219	221	224
EIRP (watts)	0.03	0.05	0.1	0.3	0.5	1	3	5	10	30	50	100
Compatibility Requirement Reduced by (dB)	Stage 2: Reduced compatibility requirement allows reduced distances for the same EIRP and effective antenna height. From the row below with the appropriate reduction in protection find the proposed EIRP and then read the new distance above from that column. EIRP(watts)											
3	0.06	0.1	0.2	0.6	1	2	6	10	20	60	100	200
6	0.12	0.2	0.4	1.2	2	4	12	20	40	120	200	399
9	0.24	0.4	0.8	2.4	4	8	24	40	80	239	398	795
12	0.48	0.8	1.6	4.8	8	16	48	80	159	476	793	1590
15	0.95	1.6	3.2	9.5	16	32	95	159	317	949	1590	3170
18	1.90	3.2	6.4	19.0	32	64	190	316	631	1900	3160	6310
21	3.80	6.3	13.0	38.0	63	126	378	630	1260	3780	6300	12600
24	7.60	13.0	26.0	76.0	126	252	754	1260	2520	7540	12600	25200
27	16.00	26.0	51.0	151.0	251	502	1510	2510	5020	15100	25100	50200
30	30.00	50.0	100.0	300.0	500	1000	3000	5000	10000	30100	50000	100000
33	60.00	100.0	200.0	599.0	998	2000	5990	9980	20000	59900	99800	200000
36	120.00	200.0	399.0	1200.0	2000	3990	12000	20000	39900	120000	200000	399000
39	239.00	398.0	795.0	2390.0	3980	7950	23900	39800	79500	239000	398000	795000
42	476.00	793.0	1590.0	4760.0	7930	15900	47600	79300	159000	476000	793000	1590000
45	949.00	1590.0	3170.0	9490.0	15900	31700	94900	159000	317000	949000	1590000	3170000
48	1900.00	3160.0	6310.0	19000.0	31600	63100	190000	316000	631000	1900000	3160000	6310000
51	3780.00	6300.0	12600.0	37800.0	63000	126000	378000	630000	1260000	3780000	6300000	12600000
54	7540.00	12600.0	25200.0	75400.0	126000	252000	754000	1260000	2520000	7540000	12600000	25200000
57	15100.00	25100.0	50200.0	151000.0	251000	502000	1510000	2510000	5020000	15100000	25100000	50200000
60	30100.00	50000.0	100000.0	300000.0	501000	1000000	3010000	5000000	10000000	30100000	50000000	100000000
63	59900.00	99800.0	200000.0	599000.0	998000	2000000	5990000	9980000	20000000	59900000	99800000	200000000
66	120000.00	200000.0	399000.0	1200000.0	2000000	3990000	12000000	20000000	39900000	120000000	200000000	399000000
70	300000.00	501000.0	1000000.0	3010000.0	5000000	10000000	30100000	50000000	100000000	301000000	500000000	1000000000

Notes:
1. Calculated distances are based on the spherical Earth diffraction loss model (loss not exceeded for 10 % of the time).
2. Protected receive level Prx=-174 dBm.
3. If a value of EIRP, effective antenna height or protection reduction is not listed then the next highest value should be used. Alternatively, the results obtained from using both the higher and lower values could be interpolated

TABLE 2: MOST directionality

Bearing Range			Relative Gain G(phi) (dB)
358	-	2	0.0
3	-	7	0.0
8	-	12	-6.3
13	-	17	-8.7
18	-	22	-10.3
23	-	27	-11.4
28	-	32	-12.3
33	-	37	-13.1
38	-	42	-13.7
43	-	47	-14.3
48	-	52	-14.8
53	-	57	-15.2
58	-	62	-15.6
63	-	67	-16.0
68	-	72	-14.3
73	-	77	-11.6
78	-	82	-3.0
83	-	87	-11.3
88	-	92	-14.0
93	-	97	-11.3
98	-	102	-3.0
103	-	107	-11.6
108	-	112	-14.3
113	-	117	-16.0
118	-	122	-15.6
123	-	127	-15.2
128	-	132	-14.8
133	-	137	-14.3
138	-	142	-13.7
143	-	147	-13.1
148	-	152	-12.3
153	-	157	-11.4
158	-	162	-10.3
163	-	167	-8.7
168	-	172	-6.3
173	-	177	0.0
178	-	182	0.0
183	-	187	0.0
188	-	192	-6.3
193	-	197	-8.7
198	-	202	-10.3
203	-	207	-11.4
208	-	212	-12.3
213	-	217	-13.1
218	-	222	-13.7
223	-	227	-14.3
228	-	232	-14.8
233	-	237	-15.2
238	-	242	-15.6
243	-	247	-16.0
248	-	252	-14.3
253	-	257	-11.6
258	-	262	-3.0
263	-	267	-11.3
268	-	272	-14.0
273	-	277	-11.3
278	-	282	-3.0
283	-	287	-11.6
288	-	292	-14.3
293	-	297	-16.0
298	-	302	-15.6
303	-	307	-15.2
308	-	312	-14.8
313	-	317	-14.3
318	-	322	-13.7
323	-	327	-13.1
328	-	332	-12.3
333	-	337	-11.4
338	-	342	-10.3
343	-	347	-8.7
348	-	352	-6.3
353	-	357	0.0

TABLE 3: MOST Frequency Response

Frequency range		Relative gain due to frequency response G(f) (dB)
<	840.0	-54.6
840.0 <=	840.1	-48.7
840.1 <=	840.2	-43.2
840.2 <=	840.3	-38.1
840.3 <=	840.4	-33.3
840.4 <=	840.5	-29.0
840.5 <=	840.6	-25.3
840.6 <=	840.7	-21.8
840.7 <=	840.8	-18.5
840.8 <=	840.9	-15.4
840.9 <=	841.0	-12.5
841.0 <=	841.1	-10.8
841.1 <=	841.2	-9.3
841.2 <=	841.3	-7.9
841.3 <=	841.4	-6.5
841.4 <=	841.5	-5.3
841.5 <=	841.6	-4.2
841.6 <=	841.7	-3.2
841.7 <=	841.8	-2.3
841.8 <=	841.9	-1.5
841.9 <=	842.0	-0.8
842.0 <=	842.1	-0.5
842.1 <=	842.2	-0.2
842.2 <=	842.3	0.0
842.3 <=	842.4	0.0
842.4 <=	842.5	0.0
842.5 <=	842.6	0.0
842.6 <=	842.7	0.0
842.7 <=	842.8	0.0
842.8 <=	842.9	0.0
842.9 <=	843.0	0.0
843.0 <=	843.1	0.0
843.1 <=	843.2	0.0
843.2 <=	843.3	0.0
843.3 <=	843.4	0.0
843.4 <=	843.5	0.0
843.5 <=	843.6	-0.1
843.6 <=	843.7	-0.3
843.7 <=	843.8	-0.7
843.8 <=	843.9	-1.0
843.9 <=	844.0	-1.4
844.0 <=	844.1	-1.8
844.1 <=	844.2	-2.6
844.2 <=	844.3	-3.5
844.3 <=	844.4	-4.6
844.4 <=	844.5	-5.8
844.5 <=	844.6	-7.2
844.6 <=	844.7	-8.8
844.7 <=	844.8	-10.5
844.8 <=	844.9	-12.3
844.9 <=	845.0	-14.4
>	845.0	-16.5

Appendix 2

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Response of the Molonglo Observatory Synthesis Telescope to Terrestrial Interference

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Abstract: In conjunction with the Australian Government's Spectrum Management Agency, experimental tests have been carried out to determine the susceptibility of the Molonglo Observatory Synthesis Telescope (MOST) to interference from terrestrial transmitters. The motivation for the tests was to reconcile the conflicting requirements of the MOST, which is committed to an extensive survey of the southern sky at 843 MHz, with the commercial use of the 825–845 MHz band, which is being prepared for sale. The tests show that the far sidelobe gain of the MOST, relative to an isotropic antenna is generally less than 1, and that an appropriate interference criterion would be that in-band interference irradiance should not exceed $-173\ \mathrm{dBWm^{-2}}$. This value is similar to that considered by the International Telecommunications Union to be detrimental to radio astronomy continuum observations at nearby frequencies.

Keywords: instrumentation: interferometers—site testing

1 Introduction

The Molonglo Radio Observatory is situated in a flat valley, ~700 m above sea level in the Great Dividing Range near Bungendore, about 30 km east of Canberra. The site was one of several considered in the mid-1950s for the 64 m radio telescope eventually built by the CSIRO at Parkes. In 1961 Bernard Mills chose the site as the most suitable for his new (408 MHz) Cross-type radio telescope (Mills et al. 1963). The land was acquired by the University of Sydney and the telescope, which became known as the One Mile Cross was opened by Prime Minister Sir Robert Menzies in November 1965. During the next 12 years the instrument was used for a number of major astronomical investigations (Mills 1991), including: production of the Molonglo Reference Catalogue of over 12 000 radio sources; discovery of supernova remnants in the Galactic Plane and the Large Magellanic Cloud; determination of accurate positions and flux densities of galaxies and quasars; discovery of a large number of pulsars including the pulsar associated with the Vela supernova remnant.

In the late 1970s it became apparent that the Cross would soon complete its planned programme of surveying the radio sky south of +18° and a decision was made to convert the east and west arms of the Molonglo telescope to an aperture synthesis instrument capable of higher sensitivity and angular resolution. This was achieved by increasing the frequency of operation by approximately a factor of two. Some constraint was imposed by the resonances of the existing line feed structure, but the choice of 843 MHz was made in consultation with Telecom to avoid likely sources of interference from radio telephony services (Mills 1981). While 843 MHz is not in an internationally protected band for radio astronomy, the use of this frequency by the Molonglo Observatory was entered as a footnote in the Spectrum Band Plan.

The Molonglo telescope in its new incarnation started observations in 1980 and has been in continuous operation, with several technical improvements, since then. It is now known as the Molonglo Observatory Synthesis Telescope (MOST). Until the early 1990s, the site proved to be free of interference in the 843 MHz band, and the MOST enjoyed quiet observing conditions. With the introduction of analogue mobile telephone services, the telescope began to experience occasional bursts of interference. At the present time (1997) such interference bursts have become much more frequent, inevitably degrading the quality of radio images and necessitating additional time consuming image processing to minimise the loss of information.

In 1995 we were dismayed to learn that the Australian Government was planning to sell the 825–845 MHz band of the electromagnetic spectrum. The use of part of this band by the MOST has been acknowledged for over 17 years, during which time the telescope has made many internationally recognised contributions to astronomy. Observations would be seriously threatened by radio frequency interference if the band were to be released for unrestricted

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use. The University entered into discussions with the Spectrum Management Agency (SMA) and it was agreed that a series of tests should be carried out to determine the sensitivity of the MOST to interfering signals from local low power transmitters. The results, together with theoretical predictions, are intended to provide the technical basis for protection of MOST observations when the 825–845 MHz band is sold for commercial use.

2 The Telescope

The MOST is a multi-element interferometer operating at 843 MHz with a 3 MHz bandwidth (FWHM). The reflectors of the MOST are two co-linear cylindrical paraboloids aligned east–west, each 11·6 m wide and 778 m long. These two *arms* are separated by a 15 m gap and have a total aperture area of more than 18 000 m^2 (Robertson 1991). The MOST incorporates 352 low noise preamplifiers, one for each 12·5 λ (4·4 m) *section*. The line feed of each section is a resonant waveguide excited by a linear array of circularly polarised ring antennas (spaced at 0·540 λ). The amplified signals from the sections are combined in groups of four, via computer controlled phase shifters, to form the 88 basic interferometer elements (*bays*) of the MOST. The intermediate frequency signals from each bay are processed to form a set of real-time fan beams, which are sampled every 24 s. The natural coordinate system for the MOST is analogous to an alt alt mounting: *tilt* is the angle of rotation of the entire structure about its east–west axis, measured from the zenith with north being positive; *meridian distance* (MD) is the angle between a beam and the plane of the meridian, positive to the west (Robertson 1991). In its usual mode of operation the MOST observes for 12 hours to form a high resolution image by the process of back projection (Perley 1979; Crawford 1984). During an observation, the bays track the chosen field centre. A mechanical drive system tilts the entire structure to the appropriate elevation. At the same time linear phase and delay gradients are applied to the line feed, thus guiding the beams in MD. The RF phase shifters are used to make small rapid offsets in the MD pointing of the bays. This facility, installed in 1995, enables the field of MOST to be widened by time sharing (Large et al. 1994). The MOST forms radio continuum images with a maximum field size of $2{\cdot}7^\circ \times 2{\cdot}7^\circ \mathrm{cosec}(\delta)$, a resolution of $43'' \times 43''$ cosec(δ) and an rms noise level of ~1 mJy per beam.

3 Beams and Sidelobes

A fan beam formed by the MOST at meridian distance θ is an arc of a small circle making an angle $(\pi/2-\theta)$ to due west. The beam has a width in MD of $\sim 30''$ sec(θ) and a width in the tilt coordinate of $\sim 2^\circ$ (FWHM). The principal sidelobes of the MOST are grating lobes arising from the periodic bay structure. They are also arcs of small circles spaced at equal intervals of sin(θ), i.e. $\sim 1{\cdot}15^\circ$ sec(θ). The grating lobes are largely suppressed as they lie near the nulls of the bay responses. The MOST is designed to receive right-hand circular (IEEE) polarisation. However, it has some sensitivity to left-hand circular polarisation, particularly for monochromatic interference for which there is no delay decorrelation. If the MOST is set to meridian distance θ, the corresponding left-hand polarisation beam is at meridian distance $-\theta$, and it too has an associated set of grating lobes.

For distant interfering terrestrial transmitters, the MOST is likely to have the greatest response at azimuths where the small circles defining the beams and gratings intersect the horizon. However, for local transmitters the MOST will be out of focus to some extent, and the gain of the beams and gratings will be correspondingly reduced. For example, for sources at a range of $\sim 1000\ \cos^2$(azimuth) km the curvature of the incoming wavefront reduces the gain of the fan beams by 10 dB. For transmitters much closer than this, recognisable fan beams are not formed. The sidelobe response is then quasi-random, relatively small, and at any given azimuth, varies rapidly with the MD setting of the telescope.

During a synthesis observation, this complicated sidelobe response structure sweeps across any fixed interfering transmitter, producing a signal in the fan beams which fluctuates at a rate dependent on the rate of change of MD. These fluctuations will be superimposed on those due to the transmitter modulation and propagation effects.

4 Theory

To provide some theoretical background for the practical tests, we consider the likely effect on the MOST of continuous narrow-band interference from a terrestrial transmitter. In practice the extent to which astronomical observations are affected will depend on a host of complex factors such as the modulation characteristics of the transmitter and the mode of operation of the MOST.

4.1 In-band Interference

If an interfering transmitter produces an irradiance I at one section of the MOST, then the interference power p in the low noise amplifier (LNA) input is

$$p = gI\lambda^2/4\pi\,, \qquad (1)$$

where g is the sidelobe gain, with respect to an isotropic antenna, in the direction of the transmitter and $\lambda^2/4\pi$ is the effective collecting area of an isotropic antenna. The noise power N, also referred to the input of one section of the MOST, is

$$N = kT_{sys}B\,, \qquad (2)$$

where T_{sys} is the system noise temperature (~100 K) and B is the bandwidth.

The voltages from the east and west arms are combined separately in the multibeaming networks. Power-linear fan beam outputs are then formed by multiplying the signals from the two arms. The ratio r of interfering signal to the rms noise fluctuations in a fan beam is

$$r = \frac{Fp}{N/\sqrt{B\tau}}\,, \qquad (3)$$

where τ is the integration time and F is a measure of the extent to which the interference signals from each section add coherently; F is 1 for a random walk addition.

If r is interpreted as the maximum tolerable interference-to-noise ratio, equations (1)–(3) can be combined to yield an expression for the maximum tolerable interference irradiance:

$$I_{\max} = \frac{r}{Fg\sqrt{B\tau}} I_0\,, \qquad (4)$$

where

$$I_0 = \frac{kT_{sys}B}{\lambda^2/4\pi} = 4\cdot 1 \times 10^{-13}\ \mathrm{Wm^{-2}}\,. \qquad (5)$$

Thus the maximum tolerable interference irradiance is proportional to the input noise power divided by the collecting area of an isotropic antenna.

To proceed we need to assign realistic values to the quantities τ, r, g and F. The appropriate value for τ is the time for which the radio telescope integrates signals coherently. For filled aperture instruments this is generally equal to the observing time, which may be many hours. For interferometers the appropriate time is the *lobe sweep time*, typically measured in seconds (International Telecommunication Union *Handbook on Radio Astronomy*—subsequently referred to as ITU 1995). During a normal 12 hour MOST synthesis observation celestial signals add coherently, but an interfering signal lasting for much longer than one 24 s sampling time would tend to add incoherently into the synthesised image. A suitable value for τ in equation (3) would appear to be $\tau = 24$ s. In this 24 s sample time an 'acceptable' interference level would be 10% of the rms noise. While this factor is to some extent arbitrary, it conforms with the guidelines specified by the International Telecommunication Union (ITU 1995). Thus in equation (3) we set $r = 0\cdot 10$. The factor g is the sidelobe gain of a section of the MOST far from the main beam. It varies considerably with telescope pointing and the azimuth of the interfering transmitter. Provisionally we adopt the value $g = 1$, which is equivalent to saying that the gain of one section of the MOST in the direction of the transmitter is equal to that of an isotropic antenna. Interfering transmitters will generally be in the near-field of the MOST (i.e. out of focus) and at a large angular distance from the MOST fan beams. Consequently interfering signals from each section of the MOST will add essentially incoherently and the appropriate value of F in equation (3) is $F = 1$. The product Fg is the sidelobe gain, relative to isotropic, of the whole telescope. Substituting the above values of τ, r, g and F into equation (4) yields

$$I_{\max} = 4\cdot 9 \times 10^{-18}\ \mathrm{Wm^{-2}}$$
$$= -173\ \mathrm{dBWm^{-2}}\,. \qquad (6)$$

This expression for the tolerable interfering irradiance is subject to the uncertainties indicated in the above discussion. In particular we have taken the sidelobe gain of the MOST to be unity. Experimental values of the sidelobe gain based on the current series of tests are presented in Section 5.

4.2 Out-of-band Interference

Signals strong enough to overload the MOST receiver system can produce interference by intermodulation. By this mechanism, transmitters well outside the MOST passband can generate interference in the output. The effect is dominated by the third-order term in the receiver response. Intermodulation interference occurs when two sufficiently strong signals have frequencies such that $(2f_1 - f_2)$ lie within the MOST passband. The magnitude of the interference, expressed as an equivalent in-band power p_e at the receiver input, is given by

$$p_e = \frac{p_1^2 p_2}{\gamma^2}\,, \qquad (7)$$

where p_1 and p_2 are the powers generated in the receiver input and γ is the third-order input intercept for the receiver. The third-order input intercept is a theoretical point on the RF input versus IF output curve where the desired input signal and third-order products become equal in amplitude as the RF input is raised (Mini-Circuits *RF/IF Designer's Handbook* 1992). Combinations of signals from three transmitters, or from one transmitter, and the input noise can also produce intermodulation interference.

To see how these effects arise in the MOST consider Figure 1 which shows a simplified block diagram of the receiver system and sketches of the frequency response at each stage. Transmitters with frequencies lying within the passband of the feed system can generate intermodulation interference in the LNAs, for which the measured third-order input intercept is $\gamma_{LNA} = -65 \pm 3$ dBW. The MOST is more sensitive to intermodulation interference from transmitters with frequencies lying within the band of the interdigital filter. The non-linearity then occurs in the first stage of the IF amplifier, the third-order input intercept, having a measured value $\gamma_{IF} = -78 \pm 5$ dBW. The sensitivity of the MOST to (two) out-of-band transmitters can be calculated by using these data and equation (7) in place of equation (1) to express the interference power developed at the input to one section of the telescope.

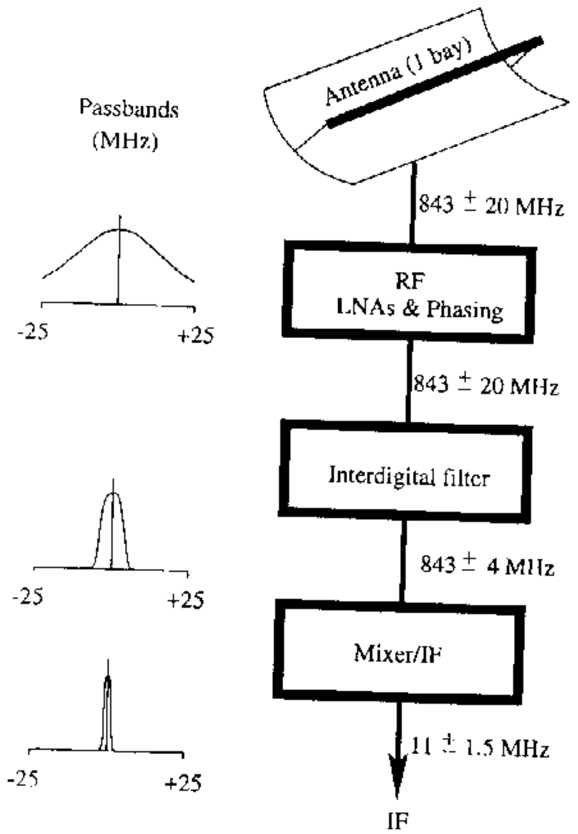

Figure 1 Block diagram showing passbands at critical stages in the signal path for one *bay* of the MOST. Sufficiently strong signals within the passband of the feed can generate interference by intermodulation in the LNAs. Similarly, signals within the narrower band of the interdigital filter can generate interference by the same mechanism in an IF amplifier.

4.3 Overall Sensitivity of the MOST

Figure 2 shows the expected sensitivity of the MOST to interference as a function of frequency. It is based on the preceding discussion and knowledge of the band shapes of the feed system, interdigital filters and IF amplifiers. The sensitivity to intermodulation arising between two transmitters generating equal power in the LNA inputs is typically 80–100 dB below the sensitivity to in-band interference. Two other typical power levels are marked on the graph for reference. These are the level of interference recognised by the ITU (1995) as detrimental to continuum radio astronomy (threshold of ~-183 dBWm^{-2} interpolated from nearby frequencies), and the MOST rms noise level of ~1 mJy, seen in a 12 hour synthesis image.

5 Test Transmissions

A series of tests were carried out in conjunction with the SMA and the Department of Communication and the Arts (DCA). The DCA mobile test transmitting equipment was set up, over 8 days in 1996 between July 22 and August 28, at four different elevated sites. The test sites, chosen to be representative of the future locations of transmitters, were situated to the west and north of the MOST at distances ~30 km. The details are given in Table 1.

Table 1. Transmission site details

Site	Mt Taylor	Red Hill Lookout	Mt Ainslie	St Georges Hill
Bearing from MOST (°)	271	281	296	354
Distance (km)	31·7	28·4	26·6	36·6
Measured path loss (dB)	142	140	153	142

After preliminary tests the transmitter frequency was set within the MOST's bandpass at 844 MHz (vertically polarised carrier, 20% AM modulated with a 1 kHz tone). The effective isotropic radiated power (EIRP) was adjusted to avoid saturation of the MOST receiver and was switched on/off at 2 (or 5) minute intervals. The SMA/DCA team set up a standard antenna and calibrated receiver to measure the irradiance at the MOST. Both the receiver and transmitter antenna heights were set at 5 m.

5.1 Measurements of the Remote Sidelobes of the MOST

The purpose of these tests was to determine the typical sensitivity of the MOST to interference from the selected sites. For each transmitter location the MOST was steered to 5 tilts (±54°, +30° & 0°) and 5 meridian distances (±60°, ±30° & 0°) making up a grid of 25 pointings.

The signals received by MOST during these tests were recorded in two ways:

(1) The signal from one fan beam was recorded on a chart recorder with a 0·5 s time constant.
(2) The usual MOST data acquisition system was used to calculate the rms signal across all 64 fan beams using a 24 s integration time.

On each day of testing a strong unresolved celestial radio source was observed in order to calibrate both the analogue chart records and the digital data acquisition system.

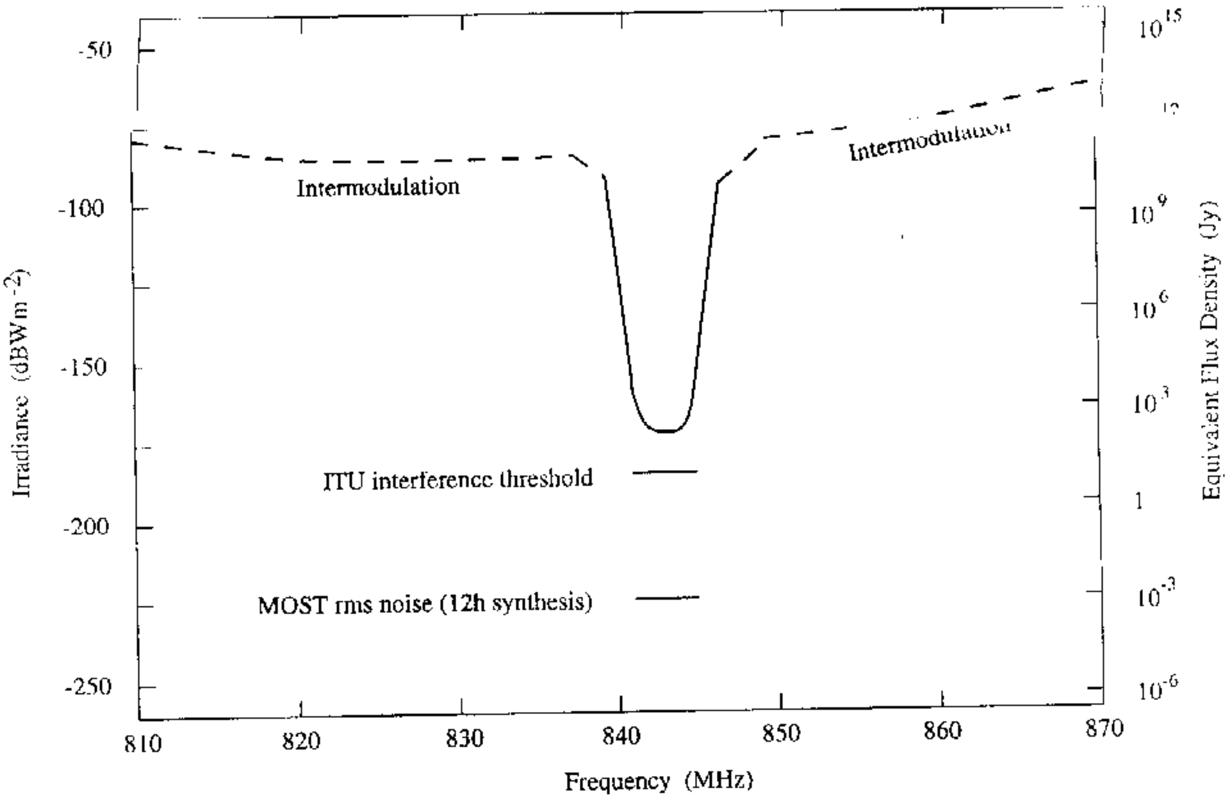

Figure 2 Expected sensitivity of the MOST to interference. The solid curve represents the response to in-band interference. Intermodulation caused by two out-of-band interference transmitters is represented by the dotted curves. The equivalent flux density is the irradiance/bandwidth expressed in Janskys.

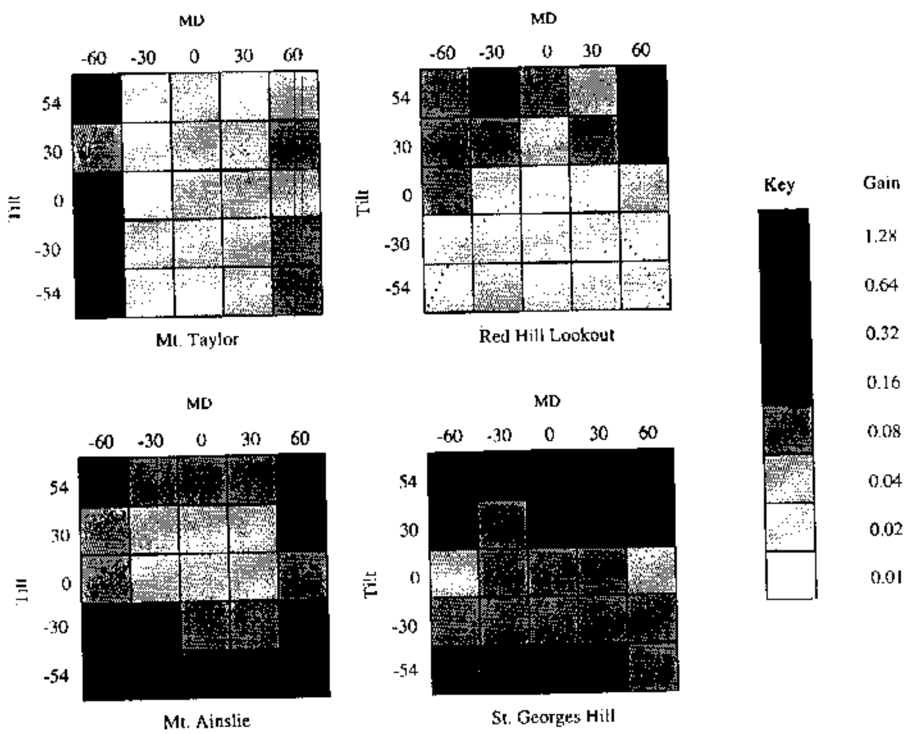

Figure 3 The sidelobe gain of the MOST shown as a function of tilt and meridian distance for the four test sites. The darker shadings indicate a higher gain value according to the key shown. The dotted line on the Red Hill site shows the track of the MOST in tilt and MD during the synthesis observations.

The chart recorder measurements of a single beam showed large short-term amplitude variations even though the signal from the calibrated test antenna was steady. These fluctuations are thought to be caused by time variable distortions of the incoming wave front over the 1·6 km length of the MOST.

As the digital data acquisition system integrated the signal over 24 s, we were concerned that some of the fine structure in the interference response might be smoothed out. A detailed comparison of the chart records and the digital results showed that the interference peaks were rarely more than 2 or 3 times the rms signal measured digitally. Accordingly we have used the digital data for subsequent analysis.

The data for all sites and telescope positions are presented not as the observed signal strength but as corresponding sidelobe gains of the MOST. These gains are calculated using the known equivalent flux density of the transmitter and the gain ($1 \cdot 0 \times 10^6$) of the MOST main beam. Figure 3 illustrates the different gain levels observed for the four interference sites. The mean gains for the sites are given in Table 2.

Table 2. Mean gains of the MOST

Site	Mt Taylor	Red Hill Lookout	Mt Ainslie	St Georges Hill
Mean gain	0·06	0·12	0·13	0·16

The average gain over all sites and telescope positions is $\sim 0 \cdot 1$. Examination of the detailed results shows that the gain varies from $\lesssim 0 \cdot 01$ to $\gtrsim 1$. The scatter among the individual pointings may arise because we have grossly undersampled the complex sidelobe structure of the telescope, as discussed in Section 3. For the three westerly transmitters there is a slight tendency for the gain to increase with MD. This is not surprising as at high MD the main beam (or the left-hand polarised beam) is directed towards the west. The average gain for the Mt Taylor transmitter, situated almost due west, appears to be lower than the other three sites, but this is barely significant in view of the scatter. Overall the gain for St Georges Hill (north) is slightly higher than for the other sites and shows little variation with MD. It is perhaps surprising that the gain remains relatively high even when the MOST is tilted to the south where one would expect the reflector to screen the line feed from interference. In the next section we describe the results of interference measurements made continuously during a 12 hour synthesis observation.

5.2 Synthesis Observations

Two tests were made to determine the susceptibility of the MOST to interference during a normal synthesis observation. The first was a reference observation taken on 1996 August 4 with no interference transmissions. The other taken on August 28 had the test transmitter located at Red Hill Lookout. Both observations were made in the 70 arcminute mode with the field centred on R.A. 10 26 25·0, Dec. −30 46 56 (B1950). The transmitter had a 5 minute on, 5 minute off cycle with an irradiance at the MOST of $5 \cdot 6 \times 10^{-14}$ Wm^{-2}, equivalent to a flux density of $1 \cdot 9 \times 10^6$ Jy in the MOST bandwidth.

Figure 4 shows the rms signal across the 64 fan beams during the 12 hour synthesis observation taken on August 28. The transmitter shows strongly in the first and last 30 minutes of the observation. The strong broad feature in the middle of the observation is due to the Sun being recorded in a sidelobe. Short duration spikes are due to nearby out-of-band mobile phone interference. The interference seen strongly at the beginning and the end of the observation corresponds to a telescope gain g, which appears inconsistent with the measurements of the gain at fixed pointings (see Figure 3). The track of the MOST, shown as a dotted line in Figure 3, has a corresponding gain of the order 0·02 for most of the fixed pointings. In fact the strong response in the synthesis observation is the result of a known (near end-fire) grating lobe scanning through azimuth 281°, the bearing of the transmitter located at Red Hill Lookout. Figures 5a and 5b show the effect of interference on an image. These have been prepared from the two observations using standard MOST reduction software.

The image constructed from data taken on August 28 shows the effects of interference from the test transmitter as well as interference from the Sun, the strongest radio source in the sky. The horizontal structure is caused by the transmitter and the vertical structure by solar interference. It can be seen in Figures 4 and 5b that the transmitter and the Sun are contributing about equally to the degradation of the image. Observations with the MOST are usually made at night and, when daytime observations are required, the usual practice is to schedule them to avoid the Sun in known sidelobes as much as possible. Scheduling of the August 28 observation was determined by the availability of the transmitter and hence we could not avoid the Sun showing in a sidelobe.

6 Discussion

In Section 4 we analysed the expected sensitivity of the telescope to interference as a function of frequency by assigning a nominal value of 1 to the remote sidelobe telescope gain. The experimental tests have shown that this gain ranges typically from 0·01 to 1 and may be higher in directions where grating beams are formed. Thus Figure 2 may be used to define the interference tolerance of the MOST.

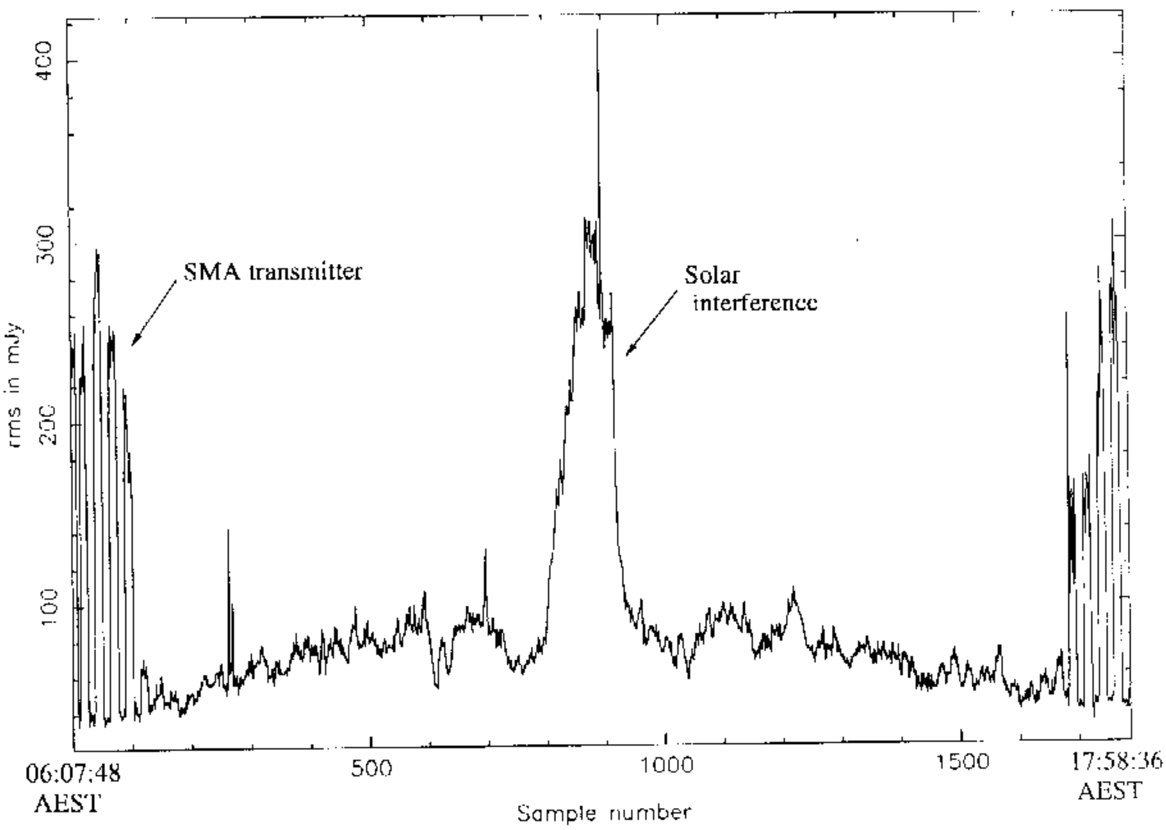

Figure 4 Data from the 1996 August 28 synthesis observation plotted as flux density (rms mJy) versus sample number. The response to the test transmitter's on/off cycle is obvious at the start of the observation (MD near −60°) and the end of the observation (MD near +60°). Solar and mobile phone interference are also visible.

The site for the telescope was originally chosen hoping that the surrounding hills would provide a measure of protection from radio interference. The interference tests with the SMA have incidentally provided an opportunity to check the level of protection afforded. By comparing the measured path losses for the four test sites with those calculated for the same distance over a smooth Earth, we find that the hills provide about 20 dB of additional protection.

The SMA has independently analysed the data from the tests and come to similar conclusions about the sensitivity of the MOST to local in-band transmitters: for the worst case the maximum tolerable irradiance is $-184\,\mathrm{dBWm^{-2}}$ (- 174 dBm in an isotropic antenna). The SMA have used the data from the collaborative tests and path loss calculations to establish criteria for restricting the future use of the 825–845 MHz band. Their report (SMA 1997) includes a table of permitted radiated powers, which would not cause detectable interference, as a function of distance and azimuth from the MOST, antenna height and frequency. As an indication of the power limits implied by the table we quote three examples. For a transmitter located 38 km north of the telescope (antenna height of 10 m) the maximum radiated power (EIRP) is 5 μW. The corresponding maximum allowable power at 66 km is 50 μW and at 99 km is 1 mW. The SMA recommendations, if adopted, would therefore rule out the use of mobile phone transmitters in the MOST passband throughout the Canberra and Queanbeyan regions.

The Australian Communications Authority (ACA), which has subsumed the Spectrum Management Agency, has used the SMA report as the technical basis for Attachment 9 of the Draft Marketing Plan for the PCS Spectrum Auction (www.aca.gov.au/spectrum/auction/pcs). Attachment 9, entitled *Radiocommunications Advisory Guidelines (Protection of Molonglo Observatory Synthesis Telescope) 1997*, sets out the compatibility requirement that would provide the MOST with a reasonable level of interference protection from transmitters. A suggested approach to assessing the compatibility is also provided. Spectrum licences in the relevant bands will require that operation of transmitters under the licence must not interfere with the MOST. This requirement to protect the MOST will cease at the end of 2008.

We believe that the ACA guidelines would adequately protect the MOST provided they are strictly followed. After the sale of the spectrum it will be the responsibility of the University to monitor interference at the observatory site and, in the event of any problems, to negotiate directly with

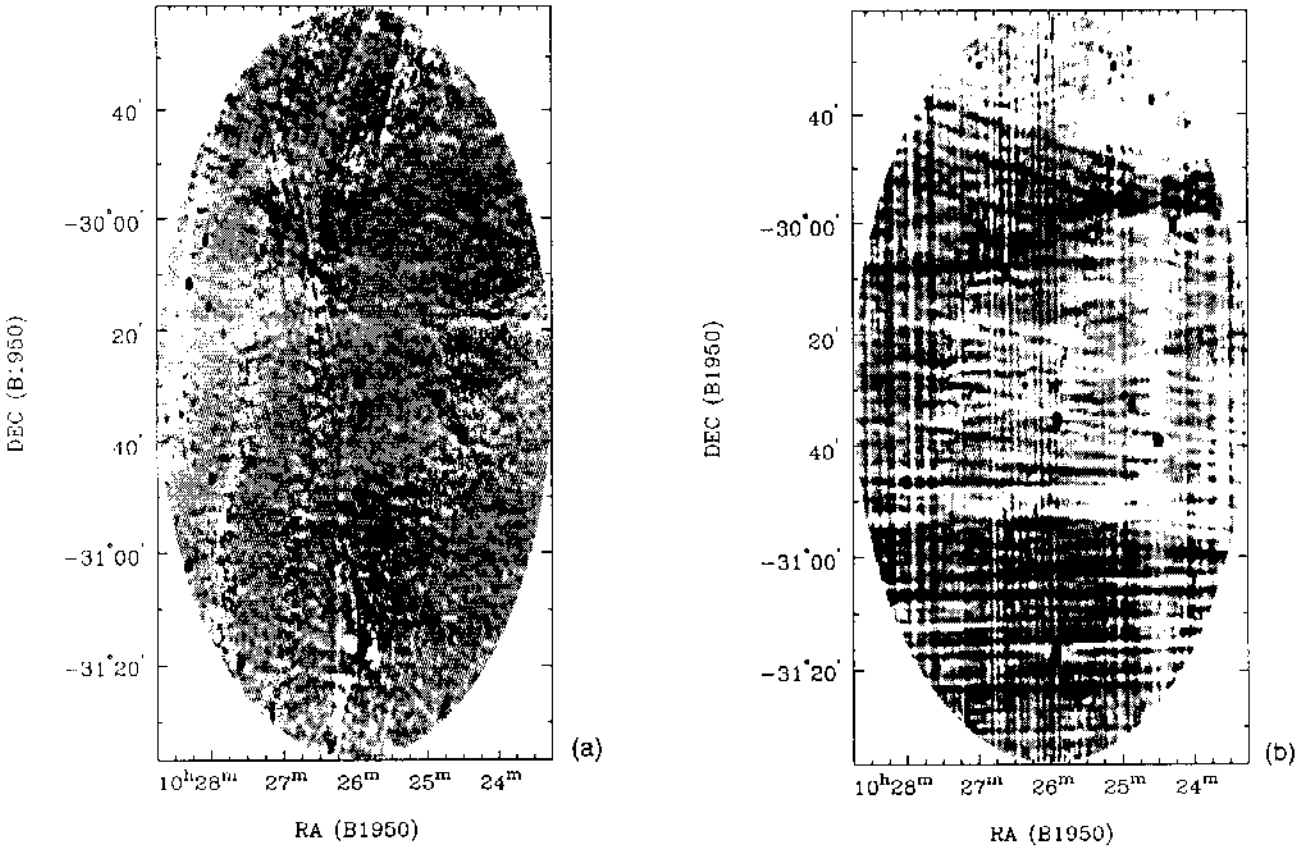

Figure 5 Images made from synthesis observations during August 1996: (a) A MOST image of the reference field from the observation on August 4. Grey-scale range is from −5 to 20 mJy per beam. (b) Image (August 28) of the same field as in Figure 5a with the transmitter on/off in a 5 minute cycle. The transmitter is responsible for the the horizontal structure. In this instance a similar degree of image degradation is cause by solar interference (vertical structure).

the users of the bands. In such negotiations the ACA would be prepared to act as a paid consultant.

At the same time the spectrum sale is proceeding, the DCA is setting up a Review of Spectrum Management Legislation to be completed by 30 June 1998 (www.dca.gov.au/whatwedo/govtrev.html). The terms of reference of this review make no mention of scientific uses of the spectrum.

7 Conclusion

The MOST forms a complex pattern of weak remote sidelobes which sweep the horizon during normal observations. The grid of 25 pointings used to measure the MOST's susceptibility to interference showed that in general the remote sidelobe gain of the telescope is ∼0·1, but these tests proved inadequate to specify the complete sidelobe pattern. In particular, they did not reveal the formation of out-of-focus grating lobes such as that found in the synthesis test. However, the collaborative test program has been broadly successful in determining the degree of protection required by the MOST to continue its high sensitivity Galactic and extragalactic radio observations.

The ITU has listed threshold levels of interference detrimental to radio astronomy continuum observations at internationally recognised frequencies for both single dish and interferometer modes of operation. Interpolating their values to 843 MHz yields a threshold of $-183\ \mathrm{dBWm^{-2}}$. The MOST is generally some 10 dB less sensitive to interference than the ITU threshold, except in the directions of grating lobes.

The ACA advisory guidelines, which are based on the analysis of the test data by the SMA, are adequate to protect the MOST.

Acknowledgments

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We thank the referee for bringing to our attention the status of the interference threshold published by the ITU.

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Appendix 3

Bull's Head Interference Incident

This has been the most prolonged and damaging interference incident to affect observational data. The severity has had a considerable detrimental affect on the quality of the science coming from the Sydney University Molonglo Southern Survey for the period 28/10/1999 to 27/7/2000. The first event was traced to a starting date in late 1999. The turn on date found by searching our image data base is 28-29/10/99 with a reporting date to the south east region office of the Australian Communications Agency on the 3/11/99.

Three techniques were eventually used to isolate and identify the signal source.

These are as follows

(a) trawling the ACA data base in the frequency and postcode domains for possible transmitter sites.

(b) from observational data approximate azimuth but not the range was determined.

(c) direction finding and identification by triangulation and localization.

In this case (a) and (b) proved indicative. The third was successful in identifying the transmitter site.

The principle problem in identification arose out of the number of communications sites which lay within the region of uncertainty determined by the observational data.

The identification was only possible after the appropriate equipment had been assembled, tested and made practical for mobile use. This consumed several man months.

Other problems were the failure to identify the frequency and the modulation mode using techniques (a) and (b).

Detection:

After several days of sorting out the origin of a number of transmissions within the Canberra-Queanbeyan region suspicion fell on a transmission emanating from a communication site 56 km west of the observatory. A surprisingly high powered wide band signal was detected and localized to Bull's Head. A Telstra communications site located on a peak west of Canberra in the Brindabella ranges.

The position and nature of the signal was immediately reported to the ACA.

Further investigation by ACA is summarized in their letter explanation. This letter highlights the technical and administrative failures which lead to this unfortunate and avoidable interference problem.

DCW

Australian
Communications
Authority

File Reference:
Your Reference: 1000719

Mr Duncan Campbell-Wilson
1152 Hoskinstown Rd
HOSKINSTOWN NSW 2621

Dear Duncan

Interference to Molonglo Radio Observatory

I refer to your recent problem of interference to your observatory.

Telstra have a radio link from Bulls Head to Brindabella Telephone Exchange. This link is assigned with a Bulls Head transmit frequency of 887MHz and a Brindabella transmit frequency of 842MHz. The Brindabella transmitter's emission will overlap with your observatory's receivers but should not normally cause a problem because of the terrain profile between Brindabella and Hoskinstown.

Apparently an officer in Telstra decided the Bulls Head / Brindabella link might cause a problem to their CDMA network and the remedy to this was to reverse transmit paths of the link (possibly about October 1999). This, obviously was done without regard to the impact neither on your observatory, nor with advice to the ACA. The usual rules of frequency assigning and relocation do not apply in this case as the link is operated under a Spectrum Licence. Spectrum Licensees are obliged to advice us of frequency co-ordination details for their devices.

However, as soon as the problem was confirmed to be the reversed link, Telstra were requested to rectify the situation. This was achieved with the willing assistance of Telstra's local Radio Tech officer.

I would like to think the matter is now settled and will not re-occur.

Yours sincerely

Bill Jones
Manager
Southern NSW Area office

2 August 2000

Purple Building, Benjamin Offices, Chan Street, Belconnen, ACT

Telephone (02) 6256 5577 Facsimile: (02) 6256 5566
Web Site http://www.aca.gov.au

Postal Address: PO Box 132, BELCONNEN ACT 2616

Appendix 4

Burra Valley RFI Incident

Date: 04-01-2001

Observation on 03-01-2001 of field centre EGS_278 was rendered useless by a new terrestrial source of interference, location unknown.

The transmissions switching on and off having abrupt transistions characteristic of a communications signal, possibly under test.

Date: 05-01-2001
Repeat observation of EGS_279 on 04/01/2001 shows continuous interference consistent with a new link having been installed.

Data Base Search:

Search of the ACA data base reveals an allocation for a link in the Burra Valley 27 kilometers south west of the telescope on a bearing of 221 degrees.

The transmitter power is 10 watts and the antenna's rear lobe is about a factor of 40 less than the forward power. The link alignment directs the rear lobe power directly at the observatory. The power radiated towards the observatory is estimated at 0.250 watts.

The frequency allocation is 840.4-841.6 MHz.

The ACA was called and the interference abruptly ceased.

Degraded images and data plots attached.

Note:

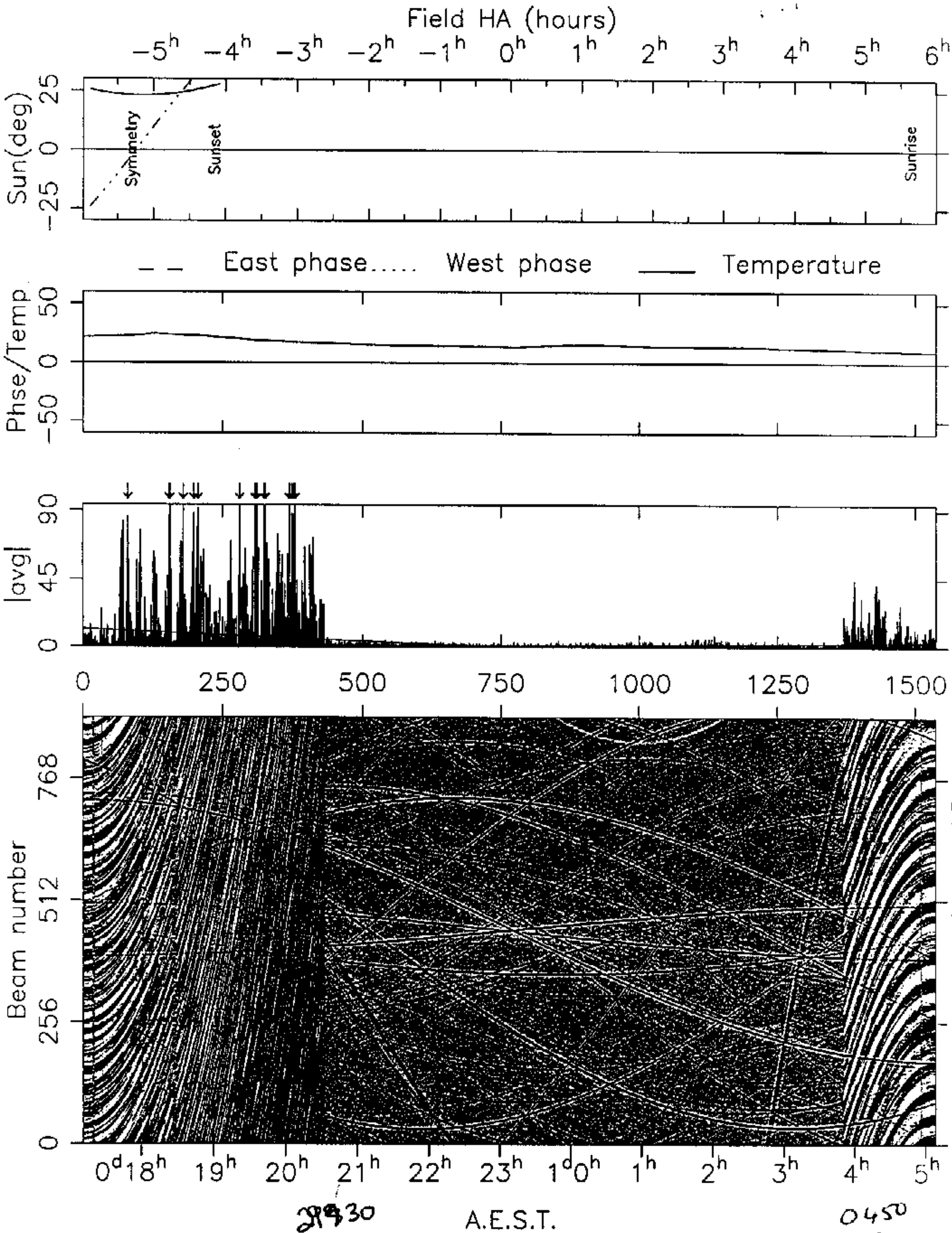
No coordination at any time between spectrum users.
Protection post incident.

DCW

New Interference

Day # 1

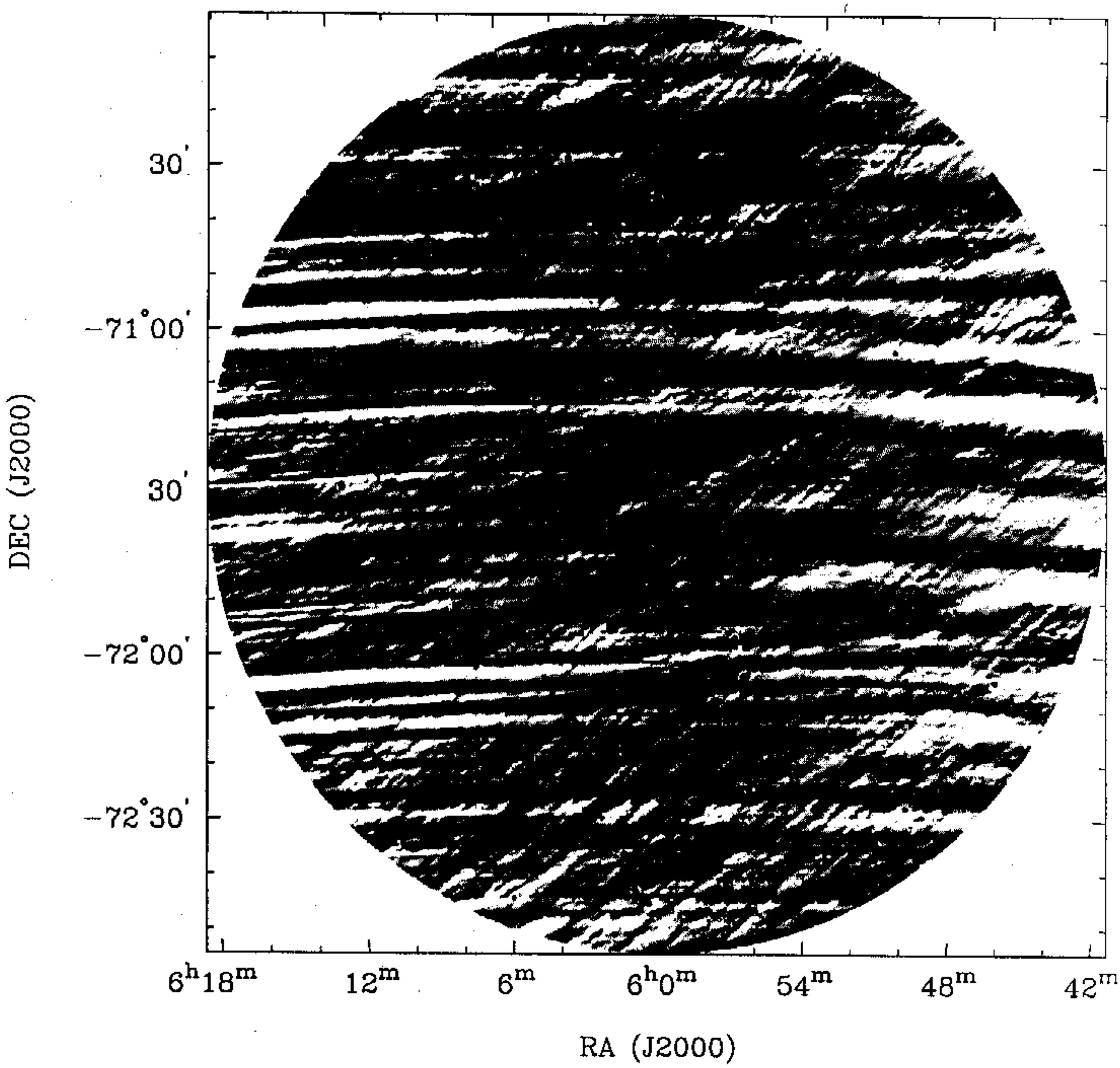
2001-01-03T17:11:23 EGS_278 0600-715:001



2030

0450 S.T.

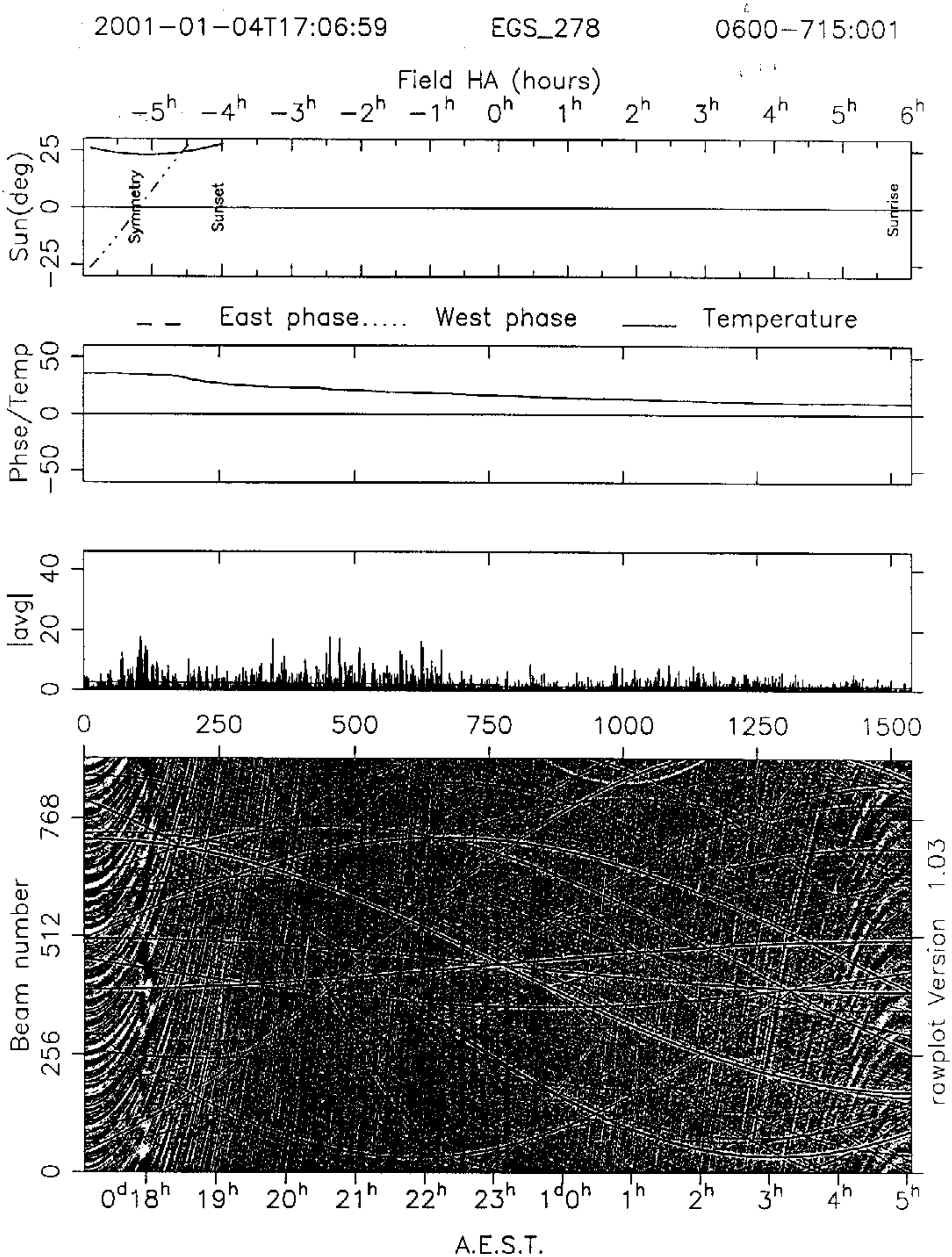
File: /CIRCINUS_1/observer/RAW/10600711C.FIT
Date Observed: 03/01/01 at 17:11:23
Object: EGS 278
Greyscale: -0.02,0.05 Jy. Map-min: -0.172 Jy Map-max: 1.07 Jy
Map centre rms: 0.01 Jy (over range -0.0209 to 0.0208)



Severe interference :

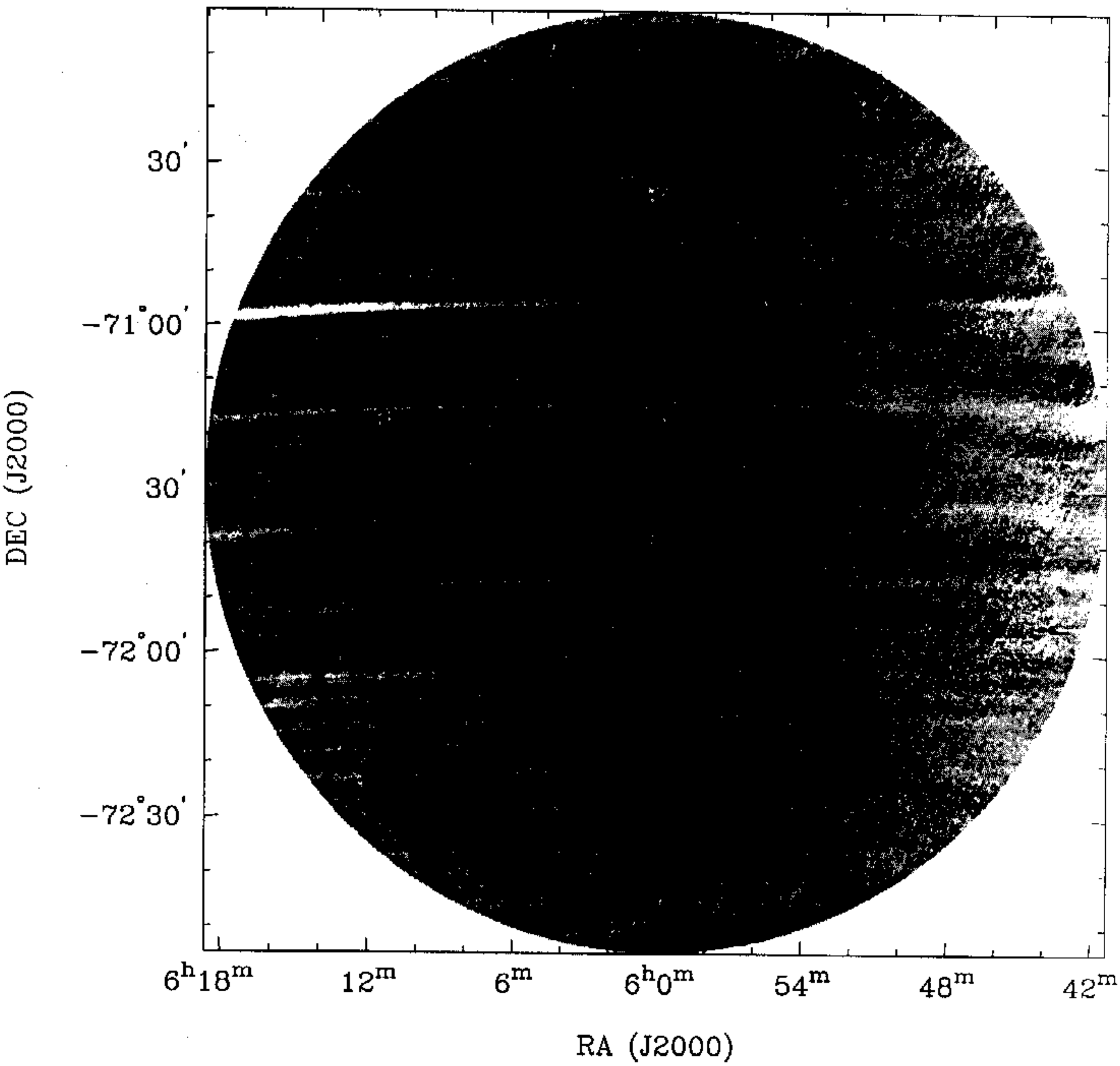
Prepared by printimage, on Thu Jan 4 13:58:45 EST 2001.

Day#2 New Interference



Interference ALL NIGHT

File: /CIRCINUS_1/observer/RAW/10600711C.FT1
Date Observed: 04/01/01 at 17:06:59
Object: EGS 278
Greyscale: -0.02,0.05 Jy. Map-min: -0.0411 Jy Map-max: 0.889 Jy
Map centre rms: 0.00263 Jy (over range -0.00716 to 0.00743)



Prepared by printimage, on Fri Jan 5 12:02:49 EST 2001.