NATIONAL RADIO ASTRONOMY OBSERVATORY
40-FOOT RADIO TELESCOPE OPERATOR'S MANUAL

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I. INTRODUCTION

The National Radio Astronomy Observatory's 40-foot diameter radio telescope was constructed in 1962 primarily to determine if the intensity of certain radio sources varies with time. It had long been known that the visual brightness of some of the stars varies with time. The radio intensity was therefore suspected to vary as well. It was not deemed practical to tie up the large telescopes for such long periods of time as required for this type experiment, so the relatively inexpensive 40-foot telescope was constructed. The telescope was used for such long term radio source variability research through 1968. After 1968 the instrument was used only occasionally as an educational tool by summer school radio astronomy students. In 1987, however, the telescope was restored to its full glory with state-of-the-art front-end equipment. The 40-foot telescope is a landmark in an historical context alone. The feed system (dipole antenna and protective radome), for example, is the original feed used at NRAO for project OZMA--the first collective scientific effort to search for communications from extraterrestrial civilizations.

The telescope's collector is a 40-foot diameter parabolic reflector constructed of steel mesh supported by a superstructure of galvanized steel. Front end receivers and accompanying equipment are fixed at the prime focus by structural supports, where the incoming radio waves are collected and focused. The electromagnetic radiation (at selected radio wavelengths) is converted to an electrical signal via the dipole antenna. The signal is then sent to a series of electronic devices in the control room that modify it to a desired form and voltage level. A signal corresponding to the intensity of the original radio source is then displayed on a strip chart recorder or some other means of data output. (See Figure 1 for a schematic diagram of the architecture of a basic radio telescope.)

40 FOOT RADIO TELESCOPE

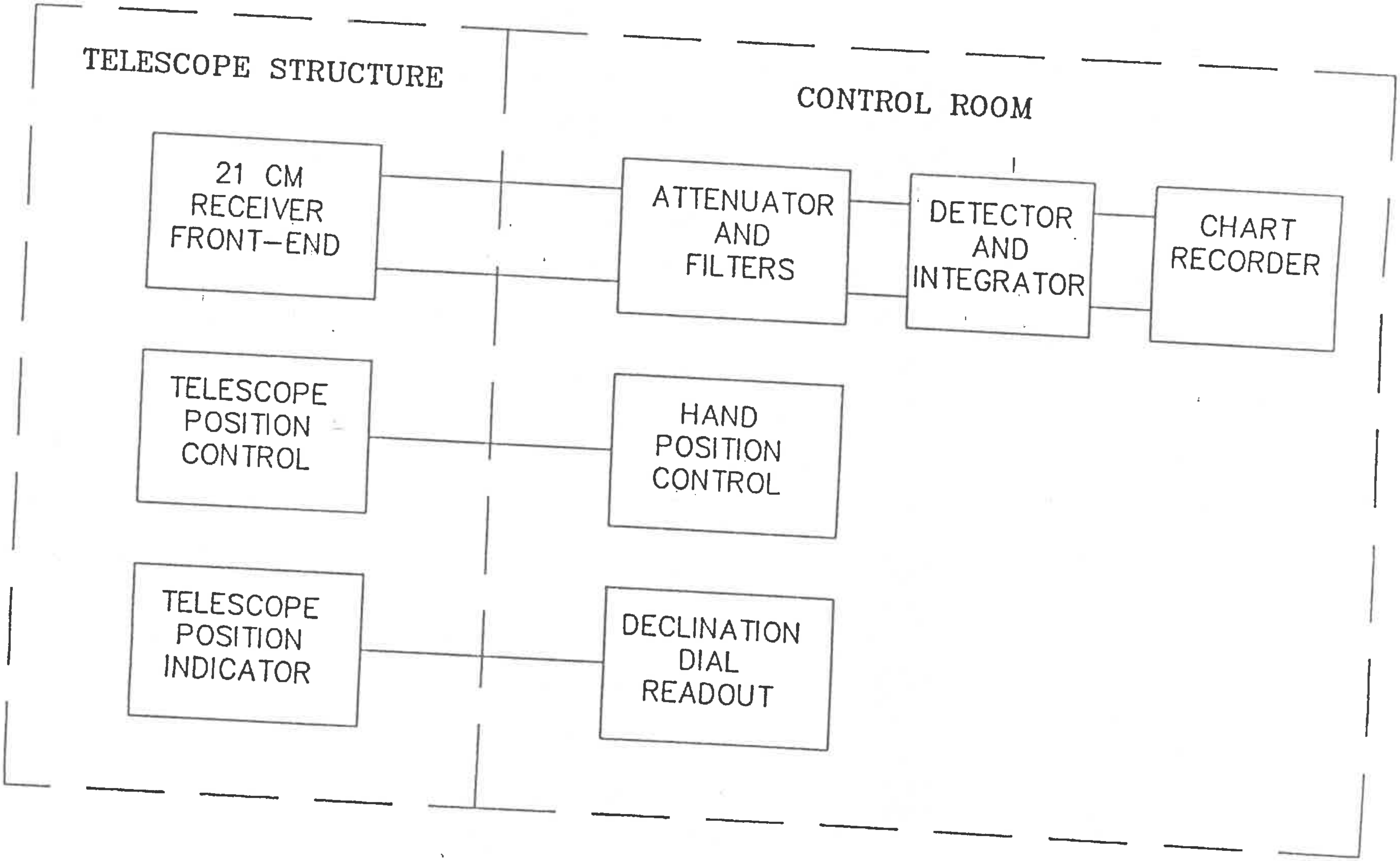


FIGURE 1

The hardware in the front end of the 40-foot telescope amplifies the signal received in excess of two million times its original intensity. Such extreme amplification is necessary due to the incredible weakness of cosmic radio signals. The radio energy collected by any telescope is inherently weak, having traversed the vast distances of interstellar space. Radio waves, like all electromagnetic radiation, dissipate according to an inverse square law--the further away the source, the weaker the signal. Only small amounts of radio energy reach the earth due to the immense distances involved. One can therefore understand the necessity of constructing telescopes with large collecting surfaces to focus these weak signals. It has been estimated that all the radio waves ever detected by all radio telescopes in the history of the science only contain as much energy as a falling snowflake.

The area of the sky observed by a radio telescope at any given time defines the beam. The angular extent of the beam is called the beamwidth. The ability to discern detailed structure in radio sources depends on the beamwidth, often referred to as resolution. The beamwidth is determined by the wavelength being observed divided by the diameter of the reflector. The equation used to determine beamwidth is therefore:

$$\alpha = (206{,}265)\ \lambda/d$$

where:

α = smallest possible angle that can be resolved (in arcseconds)

λ = wavelength observed (in meters)

d = diameter of reflector (in meters)

Note: the constant 206,265 is the number of arcseconds in one radian; used simply to convert the numbers to convenient units. The relationship λ/d otherwise gives the beamwidth in radians. The beamwidth equation is, however, only an approximation. Variables such as the fact that the effective area of the reflector tends to be much less than the actual area, reduce the equation to an approximation accurate to within about 20%. The beamwidth of the 40-foot radio telescope is therefore calculated to be around 1.0 degree of arc.

The 40-foot telescope, like the 300-foot telescope, is a transit instrument--one that moves only along the celestial meridian (along the north-south direction). Such telescopes can point to any declination (within limits), but must make use of the earth's rotation to change the aiming position in right ascension. The hour angle (difference between right ascension and sidereal time) for a transit instrument is always equal to zero. The right ascension to which the telescope is pointing, therefore, is equal to the sidereal time. It is inevitable then, that at transit (when an object crosses the celestial meridian), the right ascension of the object is equal to the sidereal time at that meridian. To observe an object with a transit instrument, the telescope is positioned at the proper declination and the earth's rotation moves the beam of the telescope across the source. In such a manner the radio waves from cosmic sources are intercepted for analysis.

graph ?

The amount of time that an object (assuming the object is a point source) remains in the beam of the telescope varies with the declination of the object even though the rotation of the earth is constant. If the 40-foot telescope were pointed at Polaris, it would observe Polaris constantly, since the declination would be +90°. The beam of the telescope would be parallel to the earth's axis of rotation and the rotation of the earth could not possibly move the beam away from Polaris. The earth rotates about its axis in approximately 24 hours. Since there are 360° in a complete circle, the earth makes an angular movement of 15° in one hour. For an object on the celestial equator, the relationship between time and angular distance is such that one hour is equivalent to 15° . Minimum transit times (duration times) are therefore established by the declination of the object observed. The actual time that an object remains in the beam of the telescope also depends on the angular size of the object itself. Many of the radio sources observed are extended sources, as opposed to discrete, or point sources. These extended sources produce longer deflections in the signal that are proportional to the angular size of the source.

II. HARDWARE

The heart of the hardware system in any radio telescope is the receiver system. The block diagram of the receiving system used on the 40-foot telescope is shown in Figure 2. Radio energy from an astronomical source is reflected from the paraboloidal surface which looks shiny at 21 centimeter wavelength and is focused at the apex of the telescope, similar to the way a reflector type optical telescope operates. There are two complete receivers at the focal point of the telescope. Both receivers are identical in construction and tuned to the 21 centimeter wavelength. The feed collects energy at the focal point and channels this energy to the two receivers depending on the electrical plane of polarization. Each channel amplifies the energy at the RF stages and then filters out unwanted energy on both sides of the desired radio spectrum window. The desired energy is then combined with a signal of known frequency which transforms the 1420 MHz energy (21 centimeter wavelength) to a lower frequency. However, the information contained in the 1420 MHz spectrum is preserved. The energy is then transferred to the control room by way of electrical coaxial cables. In the control room, the energy is converted to a voltage, amplified further, and averaged over a specific time known as the integration time. The integrator output drives the chart recorder pens. An increase in radio energy deflects the chart recorder pens to the right. The chart is driven by a clock which can be geared to any desired speed (within reason). The receiver bandwidth, amplifier gain, full scale temperature, integration time, chart recorder voltage span, and chart speed may be controlled by the user. However, as a starting point, set the controls to the following:

<u>Strong Signal</u>

Chart recorder:	1 Volt/centimeter 10 centimeters/hour
Square Law Detector:	Input attenuate: 5 dB; channels A & B 0-3 dB: Ch. A = 7.68 Ch. B = 10.0
Synch Detector A:	Input: 4.0 Full scale temp: 100K Scale expand: X1 Integration time: 1 sec
Synch Detector B:	Input: 4.0 Full scale temp: 100K Scale expand: X1 Integration time: 1 sec

Weak Signal

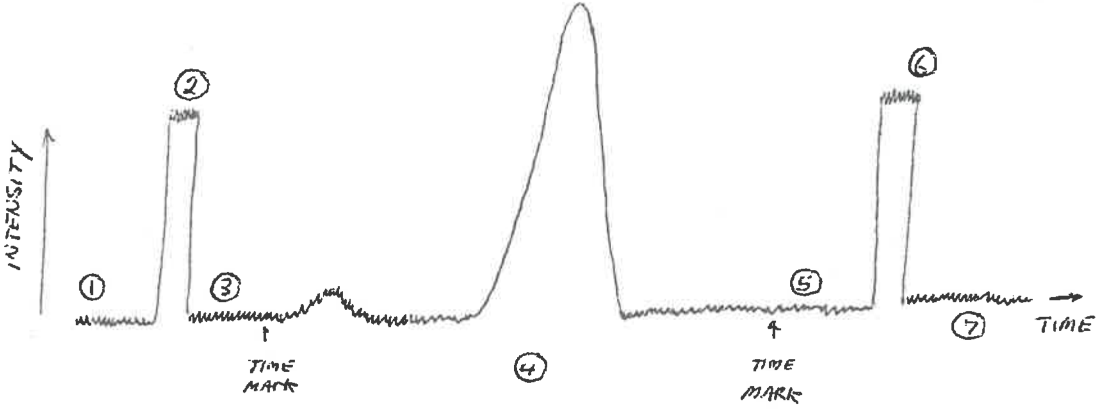
Chart recorder:	1 Volt/centimeter 10 centimeters/hour
Square Law Detector:	Input attenuate: 5 dB; channels A & B 0-3 dB: Ch. A = 7.68 Ch. B = 10.0
Synch Detector A:	Input: 7.0 Full scale temp: 30K or 10K Scale expand: X1 Integration time: 1 sec
Synch Detector B:	Input: 3.48 Full scale temp: 30K or 10K Scale expand: X1 Integration time: 1 sec

Another important data acquisition procedure is known as peaking procedure. Peaking procedures are used to determine the actual declination of a radio source once the source is in the telescope beam. After the initial deflection has occurred indicating source transit, the declination may be adjusted (with the strip chart recorder pens engaged) to provide peak deflection during source transit. Once the highest deflection has occurred, lock the telescope declination in place. The adjusted declination value corresponding to the peak deflection determines the actual declination value.

IV. SCAN PROCEDURE

In order to obtain accurate information from the telescope chart record, a radio source should be observed using the following scan procedure. A typical scan look similar to Figure 3. Declination is fixed at desired position.

FIGURE 3



1. Starting Baseline - To begin a scan, the record should show at least 5 minutes of background radiation in order to obtain a reference line so that the calibration signal can be measured.

2. Pre-Calibration - The artificial calibration source is turned on for about 2 minutes. This is used to check the receiver stability prior to observing a source.

3. Pre-Source Baseline - A baseline of at least 15 minutes should precede the time of expected source transit. This is used to obtain a reference line for source and calibration measurement.

4. Data Field - Obtain data for a specific time period. This time frame will vary depending on the desired project.

5. Post-Source Baseline - This baseline should be at least 15 minutes after the source transit. This baseline along with the pre-source baseline allows measurement of source amplitude.

6. Post-Calibration - The artificial calibration source is turned on for about 2 minutes. This is used to check the receiver stability after observing the source.

7. Ending Baseline - This baseline should be at least 5 minutes long. This is used for a reference line when measuring the calibration signal.

After the scan data is prepared in this way, the following procedure is used to analyze the data.

A. Measure the height of the two calibration signals with respect to the baseline. The average of the two measurements is taken as the calibration signal intensity.

B. Measure the right ascension and declination of all the sources in the data field. Remember, right ascension is measured along the time axis with respect to a reference. Declination can be read from the position dial.

C. Measure the height of the sources in the data field with respect to the baseline.

D. Take the ratio of source intensity to calibration source intensity. This yields the relative brightness of the radio source.

E. If the artificial calibration signal level is known then multiply the ratio in D by this value. The result is the measured brightness of the radio source.

V. LOG INFORMATION

A system log book is located next to the 40-foot control rack. This book should NEVER be removed from the room. Pages should NEVER be torn from the log book. Prior to any telescope use, the user must check the log in order to assess the system status. The following information MUST be recorded in the log by each user:

1. Name of the observer
2. Purpose of telescope use
3. Date and time (in LST) when the telescope is moved
4. The new declination
5. Receiver status
6. Start and stop times (in LST) for the scan
7. Additional comments about the scan
8. Note any problems that occur (ie. interference)

Remember the log is a record of events that have occurred. Never predict the future!

VI. CONCLUSIONS

The operation of the 40-foot radio telescope is relatively simple, revealing the efficiency of the telescope's design. Automated control systems were excluded to facilitate the understanding of the system's basic design and operation. Data acquisition is the final stage of the basic operational procedure. After the data are acquired, analysis and interpretation are ready to be performed.

APPENDIX

List of Radio Sources

Table 2

The Brightest Radio Sources Visible in the Northern Hemisphere
(Based on Observations at the 20-Centimeter Wavelength)

Name	Right Ascension			Declination			Intensity (flux units)	Identification
	hr	min	sec	deg	min	sec		
3C 10	00	22	37	63	51	41	44	Supernova remnant[a]–Tycho's supernova
3C 20	00	40	20	51	47	10	12	Galaxy
3C 33	01	06	13	13	03	28	13	Elliptical Galaxy
3C 48	01	34	50	32	54	20	16	Quasar
3C 58	02	01	52	64	35	17	34	Supernova remnant[a]
3C 84	03	16	30	41	19	52	14	Seyfert Galaxy
Fornax A	03	20	42	−37	25	00	115	Spiral Galaxy
NRAO 1560	04	00	00	51	08	00	26	
NRAO 1650	04	07	08	50	58	00	19	
3C 111	04	15	02	37	54	29	15	
3C 123	04	33	55	29	34	14	47	Galaxy
Pictor A	05	18	18	−45	49	39	66	D Galaxy[b]
3C 139.1	05	19	21	33	25	00	40	Emission nebula[a]
NRAO 2068	05	21	13	−36	30	19	19	N Galaxy[c]
3C 144	05	31	30	21	59	00	875	Supernova remnant[a]–Crab Nebula–Taurus A
3C 145	05	32	51	−05	25	00	520	Emission nebula[a]–Orion A–NGC 1976
3C 147	05	38	44	49	49	42	23	Quasar
3C 147.1	05	39	11	−01	55	42	65	Emission nebula[a]–Orion B–NGC 2024
3C 153.1	06	06	53	20	30	40	29	Emission nebula[a]
3C 161	06	24	43	−05	51	14	19	
3C 196	08	09	59	48	22	07	14	Quasar
3C 218	09	15	41	−11	53	05	43	D Galaxy[b]
3C 270	12	16	50	06	06	09	18	Elliptical Galaxy
3C 273	12	26	33	02	19	42	46	Quasar
3C 274	12	28	18	12	40	02	198	Elliptical Galaxy–M87–Virgo A
3C 279	12	53	36	−5	31	08	11	Quasar
Centaurus A	13	22	32	−42	45	24	1330	Elliptical Galaxy–NGC 5128
3C 286	13	28	50	30	45	58	15	Quasar
3C 295	14	09	33	52	26	13	23	D Galaxy[b]
3C 348	16	48	41	05	04	36	45	D Galaxy[b]
3C 353	17	17	56	−00	55	53	57	D Galaxy[b]
3C 358	17	27	41	−21	27	11	15	Supernova remnant[a]–Kepler's supernova
3C 380	18	28	13	48	42	41	14	Quasar
NRAO 5670	18	28	51	−02	06	00	12	
NRAO 5690	18	32	41	−07	22	00	90	
NRAO 5720	18	35	33	−06	50	18	30	
3C 387	18	38	35	−05	11	00	51	
NRAO 5790	18	43	30	−02	46	39	19	
3C 390.2	18	44	25	−02	33	00	80	
3C 390.3	18	45	53	79	42	47	12	N Galaxy[c]
3C 391	18	46	49	−00	58	58	21	
NRAO 5840	18	50	52	01	08	18	15	
3C 392	18	53	38	01	15	10	171	Supernova remnant[a]
NRAO 5890	18	59	16	01	42	31	14	
3C 396	19	01	39	05	21	54	14	
3C 397	19	04	57	07	01	50	29	
NRAO 5980	19	07	55	08	59	09	47	
3C 398	19	08	43	08	59	49	33	
NRAO 6010	19	11	59	11	03	30	10	
NRAO 6020	19	13	19	10	57	00	35	
NRAO 6070	19	15	47	12	06	00	11	
3C 400	19	20	40	14	06	00	576	
NRAO 6107	19	32	20	−46	27	32	13	
3C 403.2	19	52	19	32	46	00	75	
3C 405	19	57	44	40	35	46	1495	D Galaxy[b]–Cygnus A
NRAO 6210	19	59	49	33	09	00	55	
3C 409	20	12	18	23	25	42	14	
3C 410	20	18	05	29	32	41	10	
NRAO 6365	20	37	14	42	09	07	20	Emission nebula[a]
NRAO 6435	21	04	25	−25	39	06	12	Elliptical Galaxy
NRAO 6500	21	11	06	52	13	00	46	
3C 433	21	21	31	24	51	18	12	D Galaxy[b]
3C 434.1	21	23	26	51	42	14	12	
NRAO 6620	21	27	41	50	35	00	37	
NRAO 6635	21	34	05	00	28	26	10	Quasar
3C 452	22	43	33	39	25	28	11	Elliptical Galaxy
3C 454.3	22	51	29	15	52	54	11	Quasar
3C 461	23	21	07	58	32	47	2477	Supernova remnant[a]–Cassiopeia A

The coordinates are given for 1950.

One flux unit = 10^{-26} watts/meter^2/hertz.

[a] Supernova remnants and emission nebulae lie within our own galaxy.

[b] D Galaxy refers to a Dumbell-shaped galaxy.

[c] N Galaxy refers to a galaxy with a bright nucleus.

Flux units—A measure of the amount of power being received from a radio source. 1 flux unit = 10^{-26} W/m^2/Hz. This means that if the area of the radio telescope (dish-shaped say) is 100 square meters and the receiver being used has a bandwidth of 1 MHz, then the power being received which is available to deflect the pen of the chart recorder is only 10^{-18} W if a 1 flux unit radio source is being studied. Present day radio telescopes, such as the NRAO interferometer can detect radio sources whose strength is only 10^{-3} flux units. Note that the deflection produced by the radio source as measured in units of antenna temperature depends on the size of the radio telescope. Flux units are the strengths of the radio sources themselves as measured by us on earth, while the antenna temperatures measured depend on the radio telescope being used.

a. A Few Well-Known Astronomical Objects Which are Also Radio Sources

	Position (1950.0)				
	RA			Dec	
Object	*h*	*m*	*s*	*Deg*	*Min*
Andromeda nebula (M 31)	00	40	00	+41	00
Auriga A, SNR	04	57		+46	30
Cassiopeia A, SNR	23	21	11	+58	33
Centaurus A, NGC 5128	13	22	28	−42	46
Crab Nebula, M 1, SNR	05	31	30	+21	58
Cygnus A, distant galaxy	19	57	45	+40	36
Cygnus loop, SNR	20	49	30	+29	50
Cygnus X, extended EMN	20	27		+27	
Fornax A, NGC 1316	03	20	25	−37	22
HB 21 (Hanbury Brown) SNR	20	44		+50	20
Hercules A	16	48	43	+05	06
Horse's head nebula, EMN	05	38	24	−01	54
Horseshoe or Omega nebula (M 17), EMN	18	17	48	−16	09
Hydra A	09	15	43	−11	52
IC 443, SNR	06	14	36	+22	43
Kepler's SNR (1604)	17	27	43	−21	28
Lagoon nebula (M 8) EMN	18	01	00	−24	22
Magellanic cloud, small (SMC)	01	15		−73	
Magellanic cloud, large (LMC)	05	40		−69	
M 33, Sc galaxy	01	31	00	+30	24
M 77, Seyfert galaxy	02	40	12	−00	13
M 82, exploding galaxy	09	51	28	+69	56
M 101, Sc galaxy	14	01	24	+54	36
North America nebula, EMN	20	54	24	+43	52
Omega nebula (M 17), EMN	18	17	48	−16	09
Orion nebula (M 42), EMN	05	32	48	−05	27
Perseus A, NGC 1275	03	16	27	+41	21
Puppis A, SNR	08	20	18	−42	48
Rosette nebula, EMN	06	29	18	+04	57
Sagittarius A, galactic nucleus	17	42	30	−28	55
Taurus A, Crab nebula	05	31	30	+21	58
Tycho's SNR (1572)	00	22	28	+63	52
Virgo A, M 87	12	28	18	+12	40