Radioastronomy at the NASA Madrid Deep Space Communications Complex (MDSCC)

— Status Report —

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1 Introduction

The purpose of this report is to summarize the radioastronomical activities which have been performed during the second half of the year 1997 and the year 1998, using the facilities provided by the **NASA Madrid Deep Space Communications Complex (MDSCC)**. The projects performed at the MDSCC required the unique resources available at the **Deep Space Network (DSN)** such as large antennas, precise and accurate clocks, low noise receivers, wide bandwidth recorders, and high sensitivity as well as its geographical location (in the case of interferometric observations).

We note that the reported activities have been performed in the specific environment of a **NASA spacecraft tracking station**. The positive action of many individuals at JPL and at the MDSCC/INTA have been necessary for the successful accomplishment of this work. We hope that our activities have also contributed to improve the primary activities of the DSN: **tracking spacecrafts**.

More details on the radioastronomical activities can be obtained from the different authors, and in Technical Reports included in the Web-pages of the DSN radio observatory and of the MDSCC at the following URL addresses:

`http://dsnra.jpl.nasa.gov` ,
`http://www.ieec.fcr.es/gps/intro.html` ,
`http://www.laeff.esa.es/~alberdi/mdscc.html` .

2 The Radio Astronomy Program in the DSN

2.1 Segmentation

The radio astronomy program in the DSN may be devided into the following segments:

- **Applied Radio Astronomy:** Direct support of the DSN.
- **Support of the NASA:** Office of Space Sciences and Applications (OSSA).

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- **Host Country Observations:** These include both single-dish and interferometric observations.
- **Radio Astronomical Observations which require the unique capabilities of the DSN:** An agreement has been signed with the EVN (European VLBI Network) permitting the participation of the NASA dishes in a few projects, requiring very high sensitivity, in each EVN observing session. The proposals must be submitted to the Program Committees of the VLBA (Very Long Baseline Array) and of the EVN (European VLBI Network).
- **Co-observations with VSOP at 18 cm:** The co-observations were taken twice a week. Due to (i) satellite eclipse problems and (ii) malfunctioning of the satellite some planned observations could not be performed.

2.2 Instrumentation

Detailed accounts of the available instrumentation can be found in the 'Radio Astronomy and the Deep Space Network' reports generated yearly by the JPL Telecommunications and Data Acquisition Science Office, M/S 303-401, Pasadena, California 91109. Here we give a short outline.

2.2.1 VLBI Antennas

The following radio antennas are available for VLBI work:

- DSS63 (70 m)
- DSS65 (34 m)

2.2.2 Information on the DSS63

BAND	L	S	X	K
Freq. Range (GHz)	1.60-1.70	2.2-2.3	8.4-8.5	18-26*
Antenna Beamwidth (arcmin)	10.8	6.5	1.8	0.75
Apert. Efficiency(%)	60	72	65	50
Sensitivity (K/Jy)	0.84	1.0	0.9	0.7
Feed Polarization	LCP	RCP-LCP	RCP-LCP	RCP-LCP
Low noise Amplifier	FET	Maser	Maser	HEMT
Tsys (K)	35	16	21	70

* Expected to be operational in May 1999

2.2.3 Information on the DSS65

BAND	S	X	X
Freq. Range (GHz)	2.2-2.3	8.4-8.5	8.2-8.6
Antenna Beamwidth (arcmin)	16.2	4.2	4.2
Apert. Efficiency(%)	57	72	72
Sensitivity (K/Jy)	0.19	0.24	0.24
Feed Polarization	RCP-LCP	RCP-LCP	RCP-LCP
Low noise Amplifier	FET	Maser	HEMT
Tsys (K)	40	21	38

2.2.4 Recording Terminals

- 1 Mark IV A DAT (with two WCB recorders). It is controlled by the standard Linux-based field system.
- The Video Converters have 2, 4, 8 and 16 Mhz filters, with the capability to use them in the USB or LSB or both at the same time. 4 of the Video Converters have 125 KHz and 500 KHz filters available.

2.2.5 The Local Oscillators

- X Band: 8100 MHz
- S Band: 2000 MHz
- K Band: Tunable (from 18 to 26 GHz)
- L Band: 1380 MHz

2.2.6 Time and Frequency

- 2 Redundant Hydrogen MASERS.

2.2.7 Other Equipment

- SNR-8 ROGUE GPS Receiver.
- Pressure, humidity and temperature sensors integrated in the system.
- Water Vapour Radiometer.

3 News about the MDSCC

- On March 23, 1998 a *Memorandum of Understanding (MOU)* was signed between the European VLBI Network (EVN) and the NASA/JPL Telecommunications and Mission Operations Directorate (TMOD) for the use of NASA Deep Space Network. The purpose of this MOU is to establish a working relationship between NASA/JPL and the EVN:
  - The DSN Radio Observatory facilities will have *"associate member"* status within the EVN consortium.
  - The EVN will have access to schedule DSN antennas in support of EVN VLBI experiments to provide additional baselines with high sensitivity.
- The MKIV recording system is fully operational in Madrid. The MKIV terminal of the MDSCC can utilize both **thin** and **thick tapes**.

  The MkIV terminal is completely integrated in the station network via **new interface systems** [Radio Astronomy Controller (RAC) and Equipment Activity Controller (EAC)] with other peripherals (e.g. antennae, front ends, phase-cal systems, communications, etc.).
- The L-band operations at DSS63 are fully automated; the K-band operations will also be fully automated. X-band and S-band operations are not automated.
- The L-band FET LNAs were upgraded to HEMT at all complexes.
- In Canberra an S-2 VLBI system is already operational. Two S-2 recorders and S-2 DAS were purchased in order to equip also the Madrid and Goldstone 70 m telescopes. The first S-2 recorder will be installed in Madrid in Spring 1999.
- The DSN is developing a software correlator: the correlator will be completed by spring 1999. Later, the copies of this correlator will be installed at each complex in order to provide real time monitoring of the VLBI performance.

4 Experiments Performed at the MDSCC During the Year 1998

- **Euro4165:** DOY 33 – DSS65 – S/X Band
- **c9811 - EVN:** DOY 52 – DSS63 – L Band
- **GM033 - global VLBI:** DOY 53 – DSS63 – L Band
- **cb10765 - CORE-B:** DOY 70 – DSS65 – S/X Band
- **GM33-15:** DOY 95 – DSS63 – S/X Band
- **cb30965 - CORE-B:** DOY 126 – DSS65 – S/X Band
- **GB27B - global VLBI:** DOY 154 – DSS63 – S/X Band – Dual Polzn
- **ER006 - EVN:** DOY 155 – DSS63 – L Band
- **GM33-15:** DOY 157 – DSS63 – S/X Band

- **GG036 - global VLBI:** DOY 158 – DSS63 – L Band
- **Euro4398:** DOY 173 – DSS65 – S/X Band
- **BM87 - VLBA:** DOY 185-186 – DSS63 – X Band
- **BR053B - global VLBI:** DOY 193 – DSS63 – X Band – Dual Polzn
- **CORE-B 310:** DOY 210-211 – DSS65 – S/X Band
- **BR053C - global VLBI:** DOY 219-220 – DSS63 – X Band – Dual Polzn
- **Euro4498:** DOY 229-230 – DSS65 – S/X Band
- **BR053D - global VLBI:** DOY 259-260 – DSS63 – X Band – Dual Polzn
- **Euro4598:** DOY 285-286 – DSS65 – S/X Band
- **GP018 - global VLBI:** DOY 331 – DSS63 – L Band
- **GM035C - global VLBI:** DOY 334 – DSS63 – L Band
- **GB033B - global VLBI:** DOY 340-341 – DSS63 – X Band – Dual Polzn
- **Euro4698:** DOY 348-349 – DSS65 – S/X Band
- **CORE-B 312:** DOY 362-363 – DSS65 – S/X Band
- **Multiple non-VLBI radioastronomical observing sessions.**
- **Multiple VSOP co-observing sessions (2 per week).**

5 Observational Problems

Last year, different circumstances have affected the VLBI system and prevented the fringes to be found. In particular, fringes were not found between DOY 139 and DOY 160. There were several reasons:

- Station Power Failure on DOY 146.
- FTS hydrogen maser swaps on DOY's 153-160.
- Failure in the MkIV associated TCT (Time Code Translator) Unit: The TCT unit supplying 1 pps and code data to the PCFS computer was adding an extra time of +7.783 μsec to the individual experiment reported station time delay between GPS and station standard.

Besides that, some other experiments have **failed** due to operational problems.

6 Scientific Objectives and Results

The scientific objectives included the following items:

- **Study of the angular expansion of SN1993J.** A sequence of images from VLBI (DSS63 and DSS14 were essential part of the array due to their very high sensitivity) shows that the young radio supernova SN1993J has expanded with circular symmetry for nearly 5 years. Its expansion has suffered a slight deceleration and has proceeded in general accord with models of shock excited emission. To date SN1993J is the radio supernova whose evolution has been monitored in greatest detail and the one which holds

best promise for a comprehensive theoretical-observational analysis. Dual frequency monitoring of the evolution of its structure at present stages, where hydrodynamical instabilities may develop, is essential for providing data needed for modelling and theoretical analysis. The precise determination of the deceleration allows to parametrize the density profiles of the supernova ejecta and circumstellar medium (CSM) in standard supernova explosion models.

- **Study of the young radio remnant of SN1979C.** SN1979C in M100 has been one of the strongest radio supernovae, but the distance to M100 and the emission decline typical of RSN conspired to prevent a study of the structure of the radio emission by VLBI. Now the radio emission is increasing again due to the onset of a young remnant phase. The size of the remnant can be large enough to be studied by a sensitive VLBI array at 13cm and 18cm (including DSS63 and DSS14). The structure of this radio remnant might be anything from a simple shell to a very complicated structure generated by the interaction of the shock with the material deposited by a presupernova mass loss.

- **Study of the parsec-scale relativistic jets** associated with quasars and Active Galactic nuclei. DSS63 has taken part in dual polarization VLBI experiments at X-band .

- **VLBI differential astrometry**. High precision VLBI differential astrometry observations have permitted to i) study the stability of the cores of the compact radio sources and ii) determine absolute motions of the VLBI components with precisions better than a tenth of a milliarcsecond.

- **Single-dish monitoring** of variable radiostars and galactic plane variable radio sources. The 70 meter antenna (DSS63) has been used to monitor the flux density of variable radiostars (as X-ray binaries, flare stars). Several campaigns were performed coordinated with X-ray, millimetre and sub-millimetre observations at other observatories.

- **VLBI astrometry**, using the phase-referencing technique, provides submilliarcsecond-precision positions **of weakly-emitting radio stars**. Combining multi-epoch VLBI astrometric observations and Hipparcos satellite data, a low-mass companion (0.08 – 0.11 $M_{\odot}$, on the boundary between a brown dwarf and a very low-mass star) was detected orbiting the radio star AB Doradus, a member of the Pleiades Moving Cluster. This result is the first detection of a low mass stellar companion using the VLBI technique, a technique which will become an important tool in future searches for planets and brown dwarfs orbiting other stars. In fact, a whole sample of radio stars (spectral types F, G, K, M) is under study with the extremely sensitive baseline DSS63 - DSS14 at S/X bands.

- **VSOP observations at 1.6 GHz**. During the last year, DSS63 has been regularly co-observing with VSOP compact radio sources at 18cm. These observations have not been included in the previous list.

- **Applications of VLBI to Geodynamics**. The antenna DSS65 has participated in geodetic VLBI campaigns, in particular in the *Europe* and in the *CORE* experiments. The DSS65 antenna has again been surveyed in this period to determine possible displacements of the VLBI reference point. The results of different surveillance campaigns have been analyzed and intercompared.

- **Applications of GPS to Ionospheric Studies:** During the report period the GPS data from the MDSCC has been processed to study the ionosphere. The main results have been obtained with the application of occultation techniques.

- **Applications of GPS to Meteorology:** Data obtained at the MDSCC and in a local network of GPS receivers, have been used to study the spatial and temporal distribution of the atmospheric delays for meteorological applications. With the beginning of this year, we have started to produce "near real time estimates" of the total zenith delay at Madrid and Wettzell using the data stored hourly at the BKG (formerly IfAG) and CDDIS servers.

7 Recent Publications Containing Data From DSS63-DSS65

7.1 Refereed Journals

1. Alberdi, A. 1998, "Interferometría: en busca de la alta resolución en astronomía", Universo, 35, 20-29

2. Alberdi, A., Krichbaum, T.P., Graham, D.A., Greve, A., Grewing, M., Marcaide, J.M., Witzel, A., Booth, R.S., Baath, L.B., Colomer, F., Doeleman, S., Marscher, A.P., Rogers, A.E.E., Schalinski, C.J., and Standke, K. 1997, "The high frequency radio structure of 4C 39.25", Astronomy & Astrophysics, 327, 513-521

3. Elósegui, P., Rius, A., Davis, J.L., Ruffini, G., Keihm, S., Bürki, B. 1998, "An Experiment for Estimation of the Spatial and Temporal Variations of Water Vapor Using GPS and WVR Data", Physics and Chemistry of the Earth, Vol. 23, No. 1, pp. 125-130

4. Gómez, J.L., Marscher, A.P., Alberdi, A., Martí, J.M., Ibáñez, J.M. 1998, "Sub-parsec polarimetry radio observations of 3C 120: A close-up look at superluminal motion", Astrophysical Journal, 499, 221-226

5. Marcaide, J.M., Alberdi, A., Lara, L., Pérez-Torres, M.A., Diamond, P.J., Preston, R.A. 1998, "A decade of unchanged 1.3cm VLBI structure of SgrA*", Astronomy & Astrophysics, in press

6. Rius, A., Ruffini, G., Cucurull, L. 1997, "Improving the Vertical Resolution of Ionospheric Tomography with GPS Occultations", Geophysical Research Letters, Vol. 24, No. 18, p. 2291

7. Rius, A., Ruffini, G., Romeo, A. 1998, "Analysis of Ionospheric Electron Density Distribution from GPS/MET Occultations", IEEE Transactions on Geoscience and Remote Sensing, Vol. 36, No. 2

8. Ruffini, G., Flores, A., Rius, A. 1998, "GPS Tomography of the Ionospheric Electron Content with a Correlation Functional", IEEE Transactions on Geoscience and Remote Sensing, Vol. 36, No. 1

9. Ruffini, G., Cardellach, E., Flores, A., Cucurull, L., Rius, A. 1998, "Ionopheric Calibration of Radar Altimeters Using GPS Tomography", Geophysical Research Letters, Vol. 25, No. 20

10. Ruffini, G., Cucurull, L., Flores, A., Rius, A. 1998, "A PIM-aided Kalman Filter for GPS Tomography of Ionospheric Electron Content", Physics and Chemistry of the Earth, in press

7.2 Conference Proceedings

1. Alberdi, A., Gómez, J.L., Marcaide, J.M., Pérez-Torres, M.A., Marscher, A.P. 1998, "The parsec-scale radio jet of 4C39.25: witnessing the interaction between a superluminal and stationary component", in "BLLac Phenomenon", ed. L.O. Takalo, ASP Conference Series, 1998, in press

2. Alberdi, A., Gómez, J.L., Marcaide, J.M., Pérez-Torres, M.A., Marscher, A.P. 1998, "4C39.25: Multi-epoch polarization observations at 15, 22 and 43 GHz", in "EVN/JIVE Symposium No. 4", ed. M. Garrett & L. Gurvits, New Astronomy Reviews, 1999, in press

3. Alberdi, A., Lara, L., Gómez, J.L., Marcaide, J.M., Pérez-Torres, M.A., Kemball, A., Leppänen, K., Marscher, A.P., Patnaik, A., Porcas, R. 1998, "Magnetic Field Configuration in 4C39.25", in "Radio Emission from Galactic and Extragalactic Compact Sources", ed. G. Taylor, J. Wrobel and J.A. Zensus, ASP Conference Series Vol. 144, 1998, pp. 115-116

4. Alberdi, A., Lara, L., Marcaide, J.M., Leppanen, K., Patnaik, A., Porcas, R. 1997, "Dual high frequency polarization images of the quasar 3C395", in "Blazars, Black Holes and Jets", ed. M. Kidger and J.A. de Diego, Kluwer Academic Publishers (Dordrecht, The Netherlands), in press

5. Behrend, D., Rius, A. 1998, "Reference Point Stability of the DSS65 VLBI Antenna", EOS Transactions, AGU 1998 Fall Meeting, Vol. 79, No. 45, Supplement, p. F208

6. Marcaide, J.M., Alberdi, A., Ros, E., Diamond, P., Shapiro, I.I., Guirado, J.C., Jones, D.L., Mantovani, F., Pérez-Torres, M.A., Preston, R., Schilizzi, R.T., Sramek, R.A., Trigilio, C., Van Dyk, S.D., Weiler, K.W., Whitney. A.R. 1998, "Deceleration in the Expansion of SN 1993J", in "Radio Emission from Galactic and Extragalactic Compact Sources", ed. G. Taylor, J. Wrobel and J.A. Zensus, ASP Conference Series Vol. 144, 1998, pp. 353-354