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Measurements of Plasma Density and Turbulence Near the Shuttle Orbiter

by

A. TRIBBLE, N. D'ANGELO, G. MURPHY,

and J. PICKETT

Department of Physics and Astronomy
The University of Iowa
Iowa City, Iowa 52242

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ABSTRACT

In August 1985 the University of Iowa's Plasma Diagnostics Package was used in the Spacelab 2 mission to study the plasma environment near the shuttle orbiter. Measurements of the plasma density and the percentage density fluctuations yielded information about the structure of the orbiter's wake. These data appear to be in general agreement with previous shuttle results and with laboratory observations of plasma flow-body interactions.

The Spacelab 2 mission PDP (Plasma Diagnostics Package), designed and built at the University of Iowa to study the plasma and electromagnetic environment of the shuttle orbiter, was a satellite 53.3 cm in radius and 66 cm in height, which could be either positioned relative to the shuttle by the RMS (Remote Manipulator System) or ejected into free flight. One of the instruments on the PDP was a Langmuir probe, consisting of a 3 cm diameter gold-plated spherical sensor and associated electronics. The Langmuir probe was mounted on a moveable boom which was extended to a distance of about 60 cm from the cylindrical axis of the PDP during wake studies.

The Langmuir probe is a relatively simple instrument which has two operational modes, working either as an electron density/temperature measurement tool, or as a diagnostic for $\Delta N/N$ fluctuations in electron density over the frequency range 1 - 40 Hz. The electronics is alternated between the two modes by a timing signal generated by the PDP spacecraft encoder. The total cycle lasts for approximately 13 s and consists of a 12 s "lock" period during which the probe is held at +10 V relative to the PDP chassis, followed by a 1 s, 120-sample sweep from +10 V to -5 V (1).

During the lock period, the probe output current is sensed by a logarithmic sensor and sampled through three filters: 1 Hz low pass, 1 - 6 Hz bandpass, and 6 - 40 Hz bandpass. The 1 Hz filter provides a signal proportional to the plasma density, whereas the 6 - 40 Hz bandpass filter output is proportional to the percentage density fluctuation, $\Delta N/N$.

For almost one hour during the Spacelab 2 mission the PDP was positioned by the RMS at approximately 10 m directly above the orbiter cargo bay (Fig. 1). The orbiter then underwent a slow roll, at the rate of 1 degree per second, so that the PDP would pass alternately from the ram of the plasma flow into the orbiter's wake, nine times during the one-hour period. During this maneuver the orbiter's x-axis, as defined in Fig. 1, remained perpendicular to the plasma flow vector.

In Figs. 2, 3, and 4 we present samples of data obtained by the Langmuir probe during this period. Figs. 2a, 3a, and 4a show the plasma densities measured by the Langmuir probe as a function of time, while Figs. 2b, 3b, and 4b indicate, on the same time scale, the behavior of the percentage density fluctuation, $\Delta N/N$, measured by the 6 - 40 Hz bandpass filter. The data in Fig. 2 refer to daytime conditions, those in Fig. 3 are for daytime conditions until 0201:31 UT and for nighttime conditions after 0201:31 UT, while those in Fig. 4 are for nighttime conditions. During the one-hour roll period some of the thrusters on the orbiter had to be fired so that the proper attitude and roll rate were maintained. The times of thruster firing are indicated in Figs. 2, 3, and 4 by vertical arrows. Evidently, these thruster firings are responsible for some of the bursts seen in the density fluctuation data. The times at which the PDP is in the middle of the shuttle wake are indicated by asterisks.

These times are spaced one from the next by approximately 6 min, corresponding to a roll rate of 1 degree per second.

An examination of the wake transits indicates that the electron density in the wake of the orbiter is, typically, more than 2 orders of magnitude smaller than the density measured in the ram of the plasma flow, in general agreement with the results reported, e.g., by Murphy et al. (1). Density depressions are also observed when the Langmuir probe is located within the wake produced by the wrist joint of the RMS, these times being labeled by triangles (2). The arm wakes are, of course, of smaller depth and duration than the orbiter wakes.

As far as plasma density fluctuations are concerned, one notices that, in the frequency range 6 - 40 Hz, $\Delta N/N$ is, typically, on the order of 1-3% all around the shuttle orbiter. However, a special feature of this noise stands out, namely a substantial decrease of the noise within the shuttle wake, with enhancements occurring at its edges, when the Langmuir probe moves either into or out of the wake. This phenomenon has been reported and discussed previously by Murphy et al. (1). It appears also to be in line with recent laboratory observations by Merlino and D'Angelo (3) even though the laboratory scale size was much smaller. In studies of plasma flow-body interactions performed in a so-called DP (Double Plasma) device, an interesting complex noise structure in the wake of a metallic object was uncovered. The positions at which the noise amplitude is largest form an x-pattern downstream of the object. A scan of this noise pattern at just one fixed distance from the object would, of

course, have produced a result similar to the one obtained by the Langmuir probe on the PDP as it swept the ram-wake transition around the orbiter.

REFERENCES AND NOTES

1. G. Murphy, J. Pickett, N. D'Angelo, W. S. Kurth, Planet. Space Sci., Vol. 34, No. 10, pp. 993-1004, 1986.

2. Due to the rotation of the orbiter, it was necessary to rotate the PDP on the RMS in the opposite direction so that the orientation of the PDP, relative to the plasma flow, remained unchanged. As a consequence, the PDP periodically passed through the wake of the RMS.

3. R. L. Merlino, N. D'Angelo, J. Plasma Phys., in press.

4. We thank the crew of the Challenger for doing an outstanding job in performing the orbiter maneuvers and positioning the PDP on the RMS; the personnel at Johnson Space Center involved with the design and testing of RMS procedures, in particular Ann Austin; and the mission planners and Payload Operations Control Center cadre at Marshall Space Flight Center. This work was supported by grant NAG3-449 from the NASA Lewis Research Center and contract NAS8-32807 from the Marshall Space Flight Center.

FIGURE CAPTIONS

Fig. 1. Location of the PDP on the RMS, relative to the shuttle orbiter, during plasma wake studies.

Fig. 2. Plasma density (a) and density fluctuation (b) data, 0152-0158 UT, day 212, 1985.

Fig. 3. Plasma density (a) and density fluctuation (b) data, 0158-0204 UT, day 212, 1985.

Fig. 4. Plasma density (a) and density fluctuation (b) data, 0204-0210 UT, day 212, 1985.

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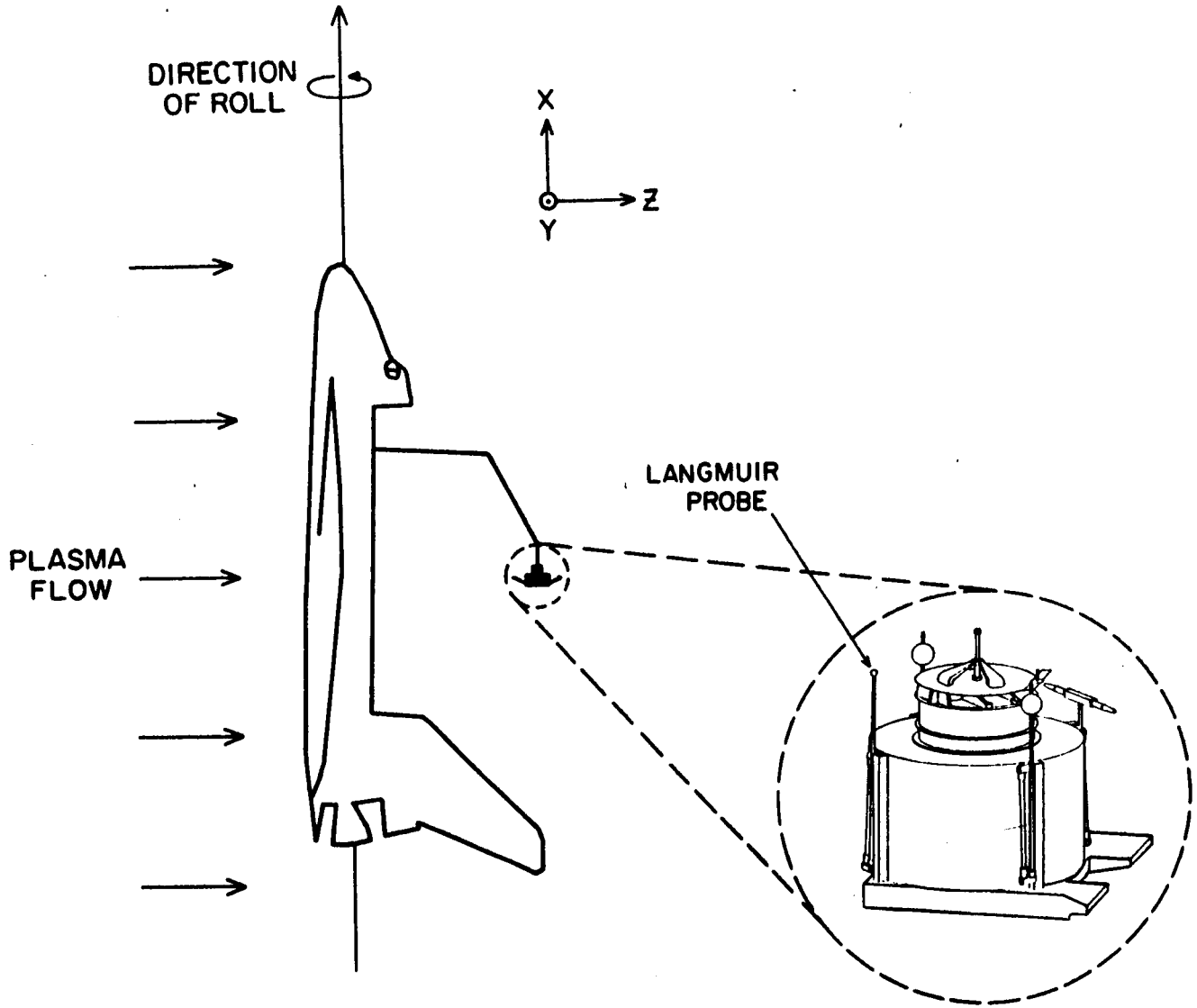
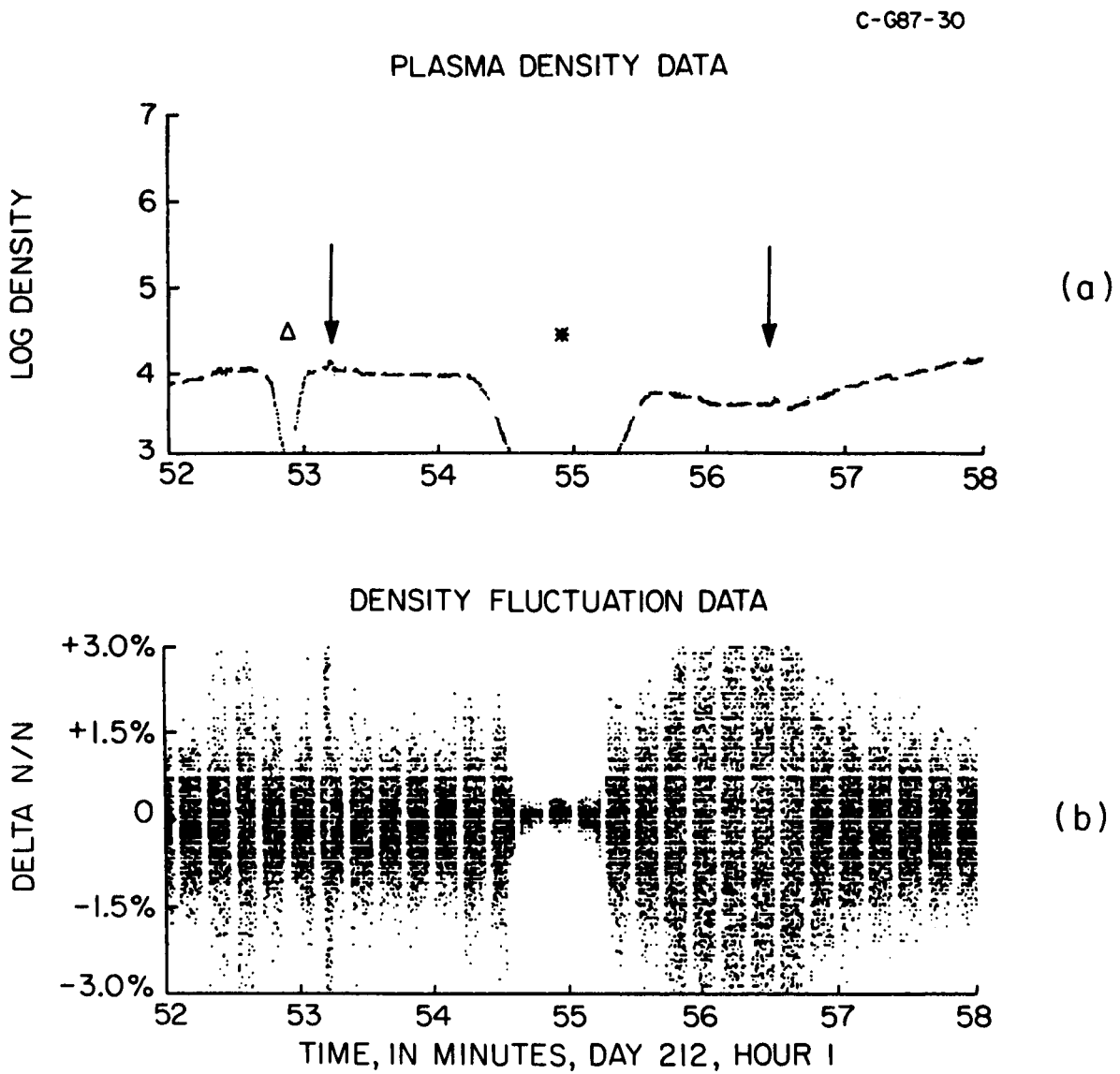
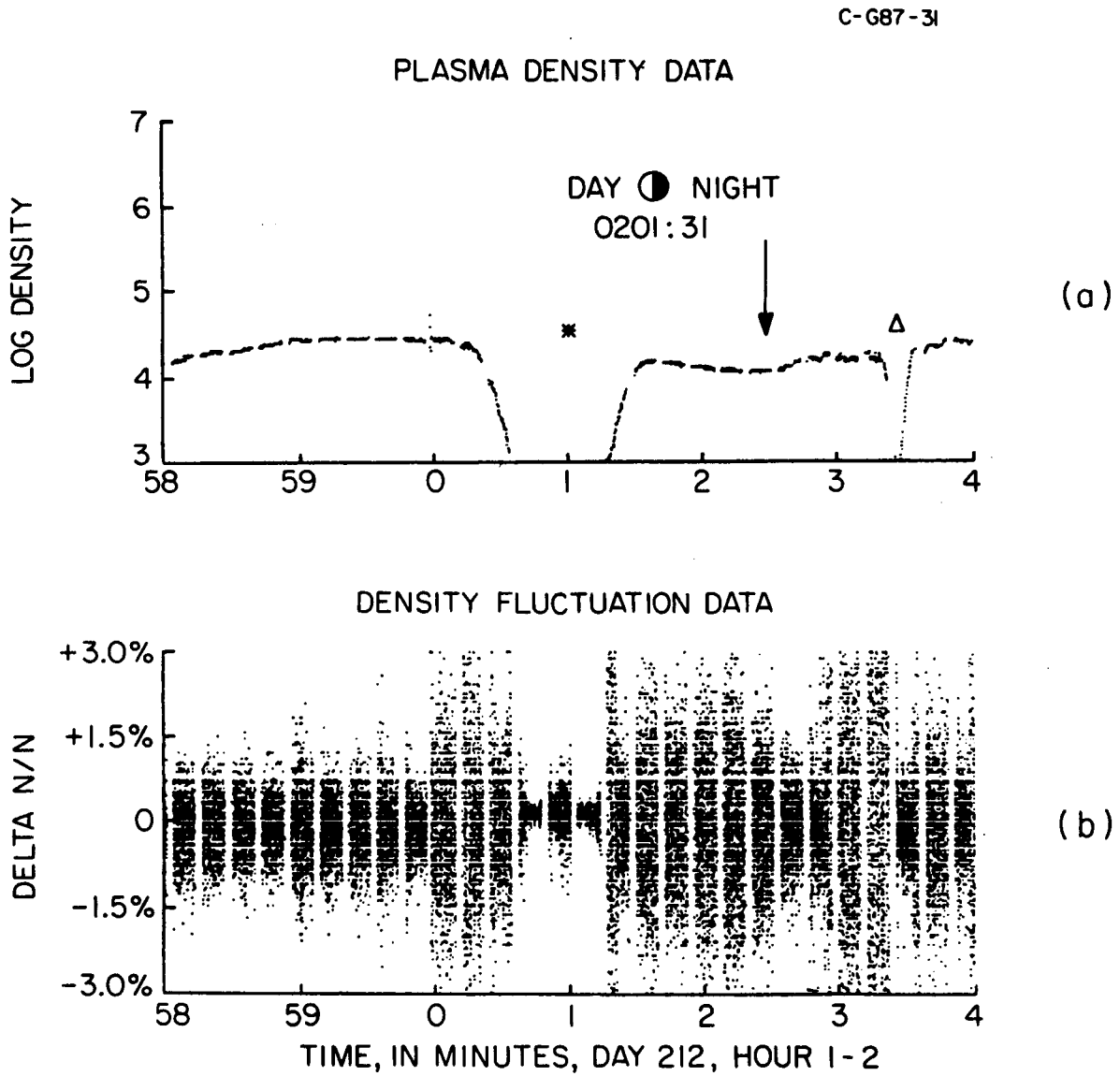
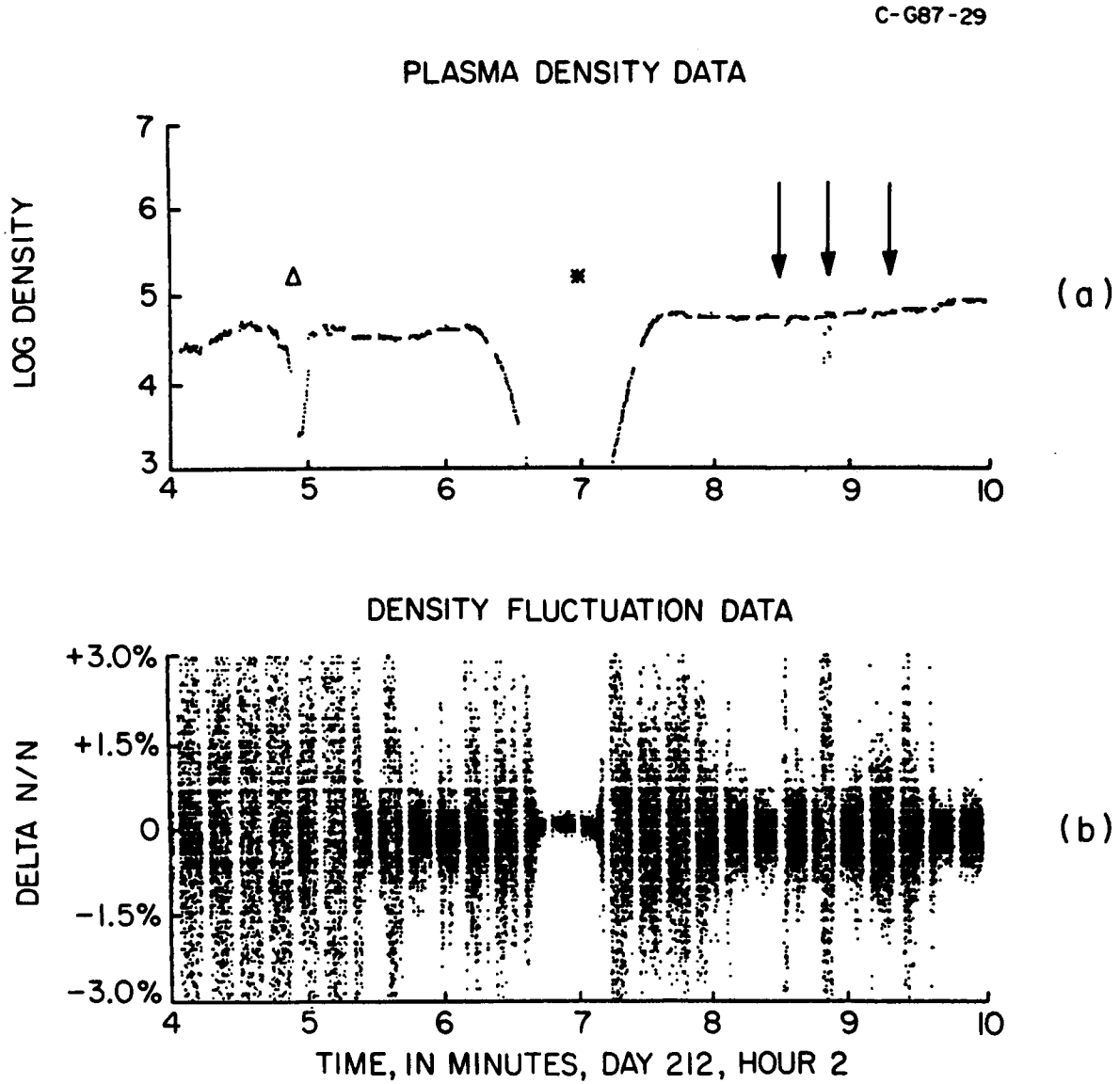



C-G87-30
PLASMA DENSITY DATA
LOG DENSITY
7
6
5
4
3
52
53
54
55
56
57
58
(a)
DENSITY FLUCTUATION DATA
DELTA N/N
+3.0%
+1.5%
0
-1.5%
-3.0%
52
53
54
55
56
57
58
TIME, IN MINUTES, DAY 212, HOUR 1
(b)


C-G87-31
PLASMA DENSITY DATA
LOG DENSITY
7
6
5
4
3
DAY ◑ NIGHT
0201:31
58
59
0
1
2
3
4
(a)
DENSITY FLUCTUATION DATA
DELTA N/N
+3.0%
+1.5%
0
-1.5%
-3.0%
TIME, IN MINUTES, DAY 212, HOUR 1-2
(b)

C-G87-29


PLASMA DENSITY DATA
LOG DENSITY
7
6
5
4
3
Δ
*
4
5
6
7
8
9
10
(a)
DENSITY FLUCTUATION DATA
DELTA N/N
+3.0%
+1.5%
0
-1.5%
-3.0%
4
5
6
7
8
9
10
TIME, IN MINUTES, DAY 212, HOUR 2
(b)