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Technical Report

"Submission of Earth-Based Ring Occultation Observations to the NASA Planetary Data System Rings Discipline Node"

Submitted by Wellesley College
to the NASA Planetary Data System
Rings Discipline Node
Ames Research Center
Moffett Field, California

DATE SUBMITTED: 2 August '93

PRINCIPAL INVESTIGATOR: Richard G. French 2Aug 93
(Signature and Date)

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PERIOD COVERED BY REPORT: 1 July 1992 – 30 June 1993

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(NASA-CR-193469) SUBMISSION OF EARTH-BASED RING OCCULTATION OBSERVATIONS TO THE NASA PLANETARY DATA SYSTEM RINGS DISCIPLINE NODE Technical Report, 1 Jul. 1992 - 30 Jun. 1993 (Wellesley Coll.) 40 p

Unclas

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I. Summary of Proposed Work

This is a technical report summarizing our progress in our program of contributing high quality Earth-based occultation observations to NASA's Planetary Data System (PDS) Rings Node. During our first year of funding, we selected five data sets for eventual inclusion in the PDS Rings Node.These were Uranus occultation observations obtained by the PI and co-workers from the IRTF of event stars U34 (26 April 1986), U1052 (5 May 1988), U65 (21 June 1990), U7872 (25 June 1991), and U7808 (28 June 1991). In our original proposal, we described four tasks:

- Data sets to a common format
- Documentation of the occultation observations and associated calibrations
- Calculation of the occultation geometry for each event
- Establish prototype PDS templates

As discussed in our renewal proposal, submitted 8 June 1993, we have completed the first three tasks, and are working on the fourth. As an indication of our progress to date, in this report we provide information about each of the data sets, their formats, the documentation, and the method used for reconstructing the occultation geometry.

II. Occultation Observations

The five data sets described below (all unpublished) were taken under a wide range of observing conditions and the occulted stars differed considerably in brightness. We have intentionally included both some of the best recent stellar occultation observations, as well as some that are marginally useful. In this way, we hope to identify problems early and to establish a flexible data storage format for the PDS that can handle both high- and low-SNR data. The main difficulties with noisy data concern proper normalization of the signal in the midst of strongly varying background signal, and unambiguous identification of real ring features. Even high SNR data can be problematical if the detector introduces spurious high frequency noise into the data, or if the time constant of the IR system is so long that ring features are significantly smeared out. In our descriptions, we will selectively highlight potential problems in preparing each of the five data sets for eventual submission to the PDS Rings Node.

U34 (26 April 1986)

These observations were obtained from the IRTF by Marc Buie. They provide a good example of the many steps involved in putting data into a common format and documenting the calibrations. The data were originally in GRABBER format, the native format for the IRTF high speed photometer. They were converted by Buie into FITS format, and provided to the PI on 9-track tape. We then converted the FITS files to our own internal standard data formats (which we call *ts* - *t*ime *s*eries and *hsp* - *h*igh *s*peed *p*hotometry) for use with our in-house plotting and model fitting software. All of the data sets in this report have been converted to *ts* or *hsp* format, and once we have worked out a final prototype PDS data template with Phil Nicholson and Mark Showalter, we will write a routine that will convert both of these data formats to the standard PDS format.

In addition to converting the data to a standard format, additional calibrations needed to be performed. For example, because the oscillator driving the data system at the IRTF was not perfect, timing signals recorded as part of the data stream had to be used to calibrate the actual data interval per point. Nominally, this was 2 msec/pt, but because of clock drift, we

determined the more accurate rate to be 1.9999702 msec/pt. As another example, microphonic pickup by the IR detector introduced considerable ripple and resonance noise into the raw data signal, and this needed to be filtered out by smoothing and by low-pass filtering. This data set has a marginal SNR for ring analysis: it is useful for ring profile modelling and ring orbit model fitting, but only after considerable pre-processing.

A compressed display of the original data set is shown in **Fig. 1**. There is considerable baseline drift, because these (like all of the data sets described here) were observed in the DC mode (rather than in chopping mode), and thus long-term background variations are not suppressed. Located in the figure are the ring and atmosphere occultations, as well as the calibrations used to determine the level of full stellar intensity. It is quite clear that an uninitiated user would have a great deal of difficulty interpreting this light curve without some documentation to identify specific features in the curves. The observing conditions during ingress (**Fig. 2**) were poor, and even in this higher resolution plot, it is difficult to identify individual ring features. Ring egress (**Fig. 3**) was more favorable, and even with wandering baselines, individual rings are distinct. An example of an atmospheric occultation is shown in **Fig. 4**, which is accompanied by an adjacent calibration check. The PDS Rings Node will need to be able to document such atmospheric occultations when they are part of the ring occultation observations as well.

The data processing necessary to produce clear ring profiles includes multi-notch and low-pass filtering, as is evident from the power spectrum of a section of the data set shown in **Fig. 5**. Note the pickup of both 60 Hz (and harmonics) as well as other strong peaks. With only modest filtering, some ingress features can be identified in the noise of **Fig. 2**, such as the γ ring profile fitted with a square well diffraction model in **Fig. 6**. The egress ε ring profile (**Fig. 7**) has high SNR but clearly shows residual high-frequency noise that has not been sufficiently filtered out. An important decision to be made when preparing these data sets for final archive is to what extent the observer/contributor should pre-process the observations, as opposed to simply supplying the raw observations with text documentation of known problems.

As an example of the data file formats we use internally, a generic template *ts* data file header is shown in **Fig. 8**, and the actual data header for U34 is shown in **Fig. 9**. In the final submitted version, we propose also to include a table giving a chronological identification of significant features in the data set such as bias level changes, sky checks, identifiable ring features, regions of cloudiness, and so forth. The final format for such a catalog will depend somewhat on the PDS occultation data format, but it will be an essential part of the documentation.

Using all of the ring features identifiable in the data set, we have reconstructed the occultation geometry and the location of the occultation chord across the rings and planet, as depicted in **Fig. 10**. Note that this is a nearly central occultation, but we found no evidence in the data of a Uranian central flash, which in any case would have been of very low amplitude for this chord because of the nearly spherical shape of the projected planet. From the solution for the occultation geometry, we can compute the equatorial plane radius probed by the occultation rays as a function of time, shown in **Fig. 11** for this event. Note that, since many of the Uranian rings are inclined, this radius scale will *not* be adequate for precise measurements of ring features, and it will be important to decide how to distinguish between true ring plane radius and equatorial radius in the final PDS products.

U1052 (5 May 1988)

This occultation was considerably higher SNR than U34, but as illustrated in **Fig. 12**, it was a grazing event, missing the planet and the inner four rings entirely (we estimate that it passed a mere 100 km away from the α ring at closest approach!). The full light curve is shown in **Fig. 13**, where individual ring features can be seen interspersed among calibration checks, and where the background level changed substantially but smoothly. These observations were obtained by Marc Buie as well, and were translated from FITS into our internal *ts* format using the simple UNIX shell scripts and header files shown in **Figs. 14-16.** The high quality of the data is illustrated in the δ ring ingress and egress ring profiles shown in **Figs. 17-18**, where the diffraction fringes are quite evident, as is the faint broad ring interior to the main part of the δ ring. There is still some unremoved ripple in the data, as seen in these figures, but midtimes of the model fits are accurate to a few msec, making them extremely useful for ring orbit determination. The results of the full set of ring profile fits are given in the table labelled as **Fig. 19**. It would seem to be useful to include such results as part of the PDS package, although the results should also eventually be in print in a refereed journal. Finally, **Fig. 20** shows the reconstructed equatorial plane radius as a function of time. It will need to be decided if each datum should be tagged with an equatorial plane radius, or whether a simple polynomial function should be fitted, with the equatorial plane radius being computable with PDS-supplied algorithms.

U65 (21 June 1990)

The occultation of U65 occurred under marginal conditions and the star was relatively faint, making this one of the poorest quality data sets still worth analyzing for ring orbital studies. The observations were made by R. French and M. Clark from the IRTF. The reconstructed occultation geometry is shown in **Fig. 21** - note that all the rings were occulted, but there was no planet occultation. The ingress light curve (**Fig. 22**) is quite noisy, and even in the egress curve (**Fig. 23**) it is challenging to identify a single convincing ring feature. It is unlikely that this data set will ever provide useful constraints on the abundance of inter-ring material, or accurate optical depths of the known rings, but ring event times are still obtainable from the data, and hence the observations are still of some value. The headers for the ingress and egress data are shown in **Figs. 24** and **25**. To illustrate the difficulty of finding ring features in the ingress data, take a look at **Fig. 26**, which shows a ring profile fit to Ring 4 (at about 9 seconds from the start of the figure). The fitted ring profile occurs at very close to the predicted time for this ring, but no great weight should be placed on the resultant fit. This raises the issue of how to flag such marginal events - this one is probably real, but at the edge of plausibility.

The situation is improved for egress, where the Ring 4 profile is easily detected (**Fig. 27**). Note the residual presence of ripples in the data due to high frequency noise in the data. It should be mentioned that these observations were made using a treble boost circuit that amplifies the high frequencies that would otherwise be suppressed by the IR electronics. Thus, it is dangerous to assume that the noise is white noise, and formal errors from least squares fits to ring are almost certainly misleading. As further evidence that good ring profiles can be found in these data, **Fig. 28** shows the egress profile of the α ring. Finally, in **Fig. 29**, we show the computed equatorial plane radius as a function of time.

U7872 (25 June 1991)

Serendipitously, two high SNR occultations were visible from the IRTF within three days of each other in June of 1991. R. French observed these events with N. Chanover and E. Mason. The reconstructed occultation geometry of U7872 is shown in **Figs. 30** and **31**. The full occultation light curve is shown in compressed form in **Fig. 32**, where bias level changes, sky checks, and guiding problems produce a welter of dips and kinks in the curve. A complete set of ingress and egress ring profile fits was performed, with the results shown in **Figs. 33** and **34.** Varying background levels are evident in a few of the ingress ring profiles (ex: β, δ, and ε), but the egress profiles are very stable and high SNR, and are among the best ever recorded.

This is an example of a relatively clean data set that should require little additional work to prepare for final submission to the PDS. It is not hard to see that there is an inverse relationship between the quality of the data and the amount of effort required to document the observations, and at some point it will need to be decided whether or not the effort is justified for the marginal data sets.

U7808 (28 June 1991)

The final data set we have processed as part of this work is the occultation of U7808, whose event geometry (**Figs. 35** and **36**) was very similar to the U7872 occultation just three days earlier. Because of the near-grazing incidence of the inner ring occultations, the ring plane radial velocity was very low, and the ring profiles were thus of extremely high SNR, particularly for the faint inner three rings (4, 5, and 6). The general character of the overall occultation light curve (**Fig. 37**) resembles that of U7872 - guiding problems during ingress were solved during egress, and the resultant ring profile fits (**Figs. 38** and **39**) show some baseline variations on ingress (η and γ) but very stable baselines for egress, and stunning diffraction fringes on the Ring 6 profile. This data set should also be relatively easy to put in final form for the PDS, once the file format has been established.

III. Future Directions

Clearly, the next step is to decide upon a template for ground-based one-dimensional photometric occultation observations for the PDS. Among the issues that make this challenging are the desire to have all data in a common format along with the competing desire for simplicity and clarity. Occultation data from the HST, IR array occultation observations, and multi-channel visual observations all have special requirements, and it will take some care to insure that the adopted formats are not cumbersome to use for data sets that don't satisfy a strict set of conditions. Because of these important questions, we have postponed constructing templates until the fall of 1993, when R. French will be visiting Phil Nicholson at Cornell for several weeks prior to the annual DPS meeting. The plan will be to develop a template and to convert one of the data sets (probably U7808) into this format. Then, at the DPS meeting, we will present these proposals to the PDS Rings Node advisory group for comment and criticism. Based on the results of these sessions, we will revise the template as needed and then proceed during the coming year with formal preparation of the data for submission to the PDS.

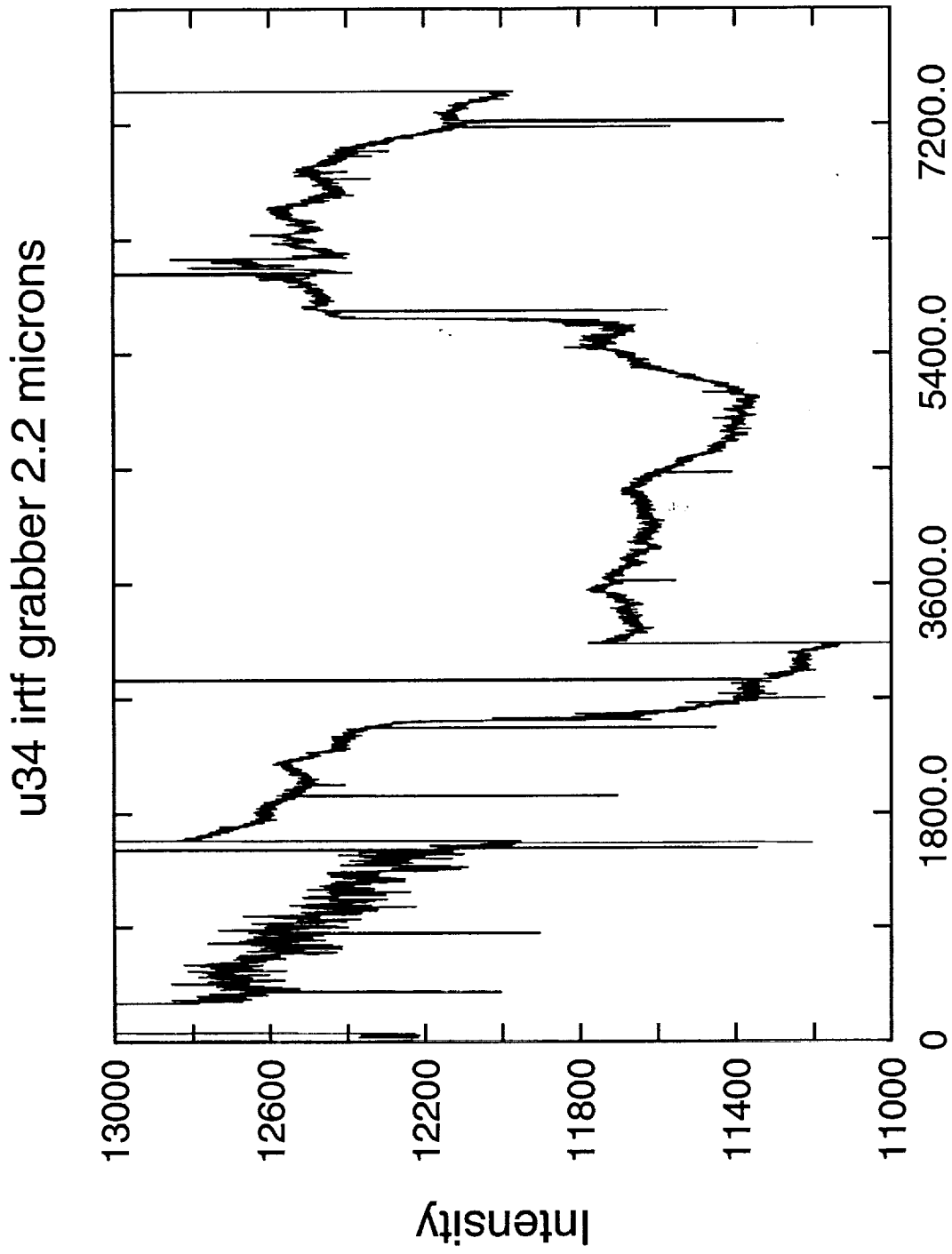

u34 irtf grabber 2.2 microns
Intensity
13000
12600
12200
11800
11400
11000
0
1800.0
3600.0
5400.0
7200.0
Seconds after 14:00:00.0000 UT

Fig 1

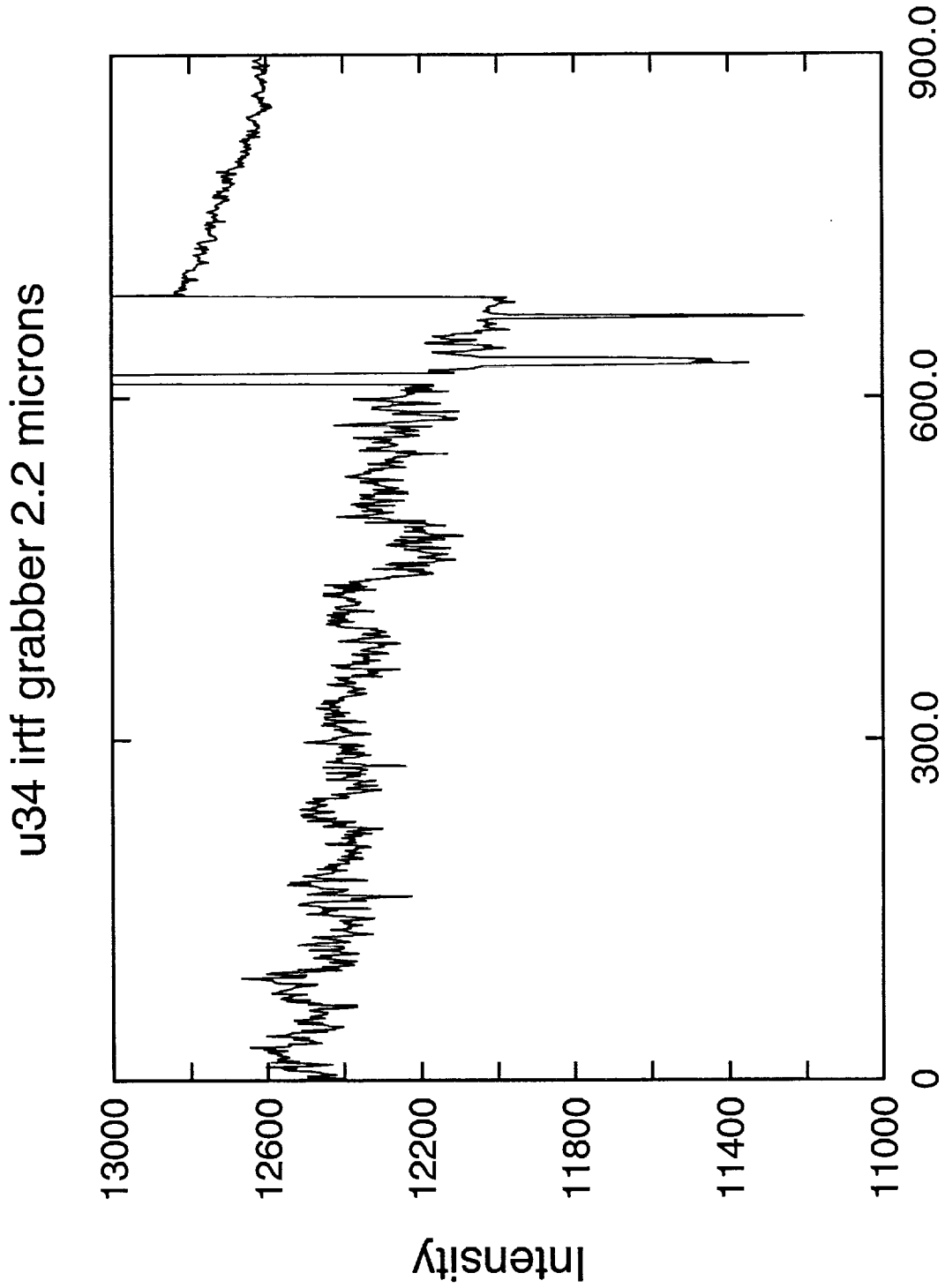

u34 irtf grabber 2.2 microns
Intensity
13000
12600
12200
11800
11400
11000
0
300.0
600.0
900.0
Seconds after 14:15:00.0000 UT

Fig. 2.

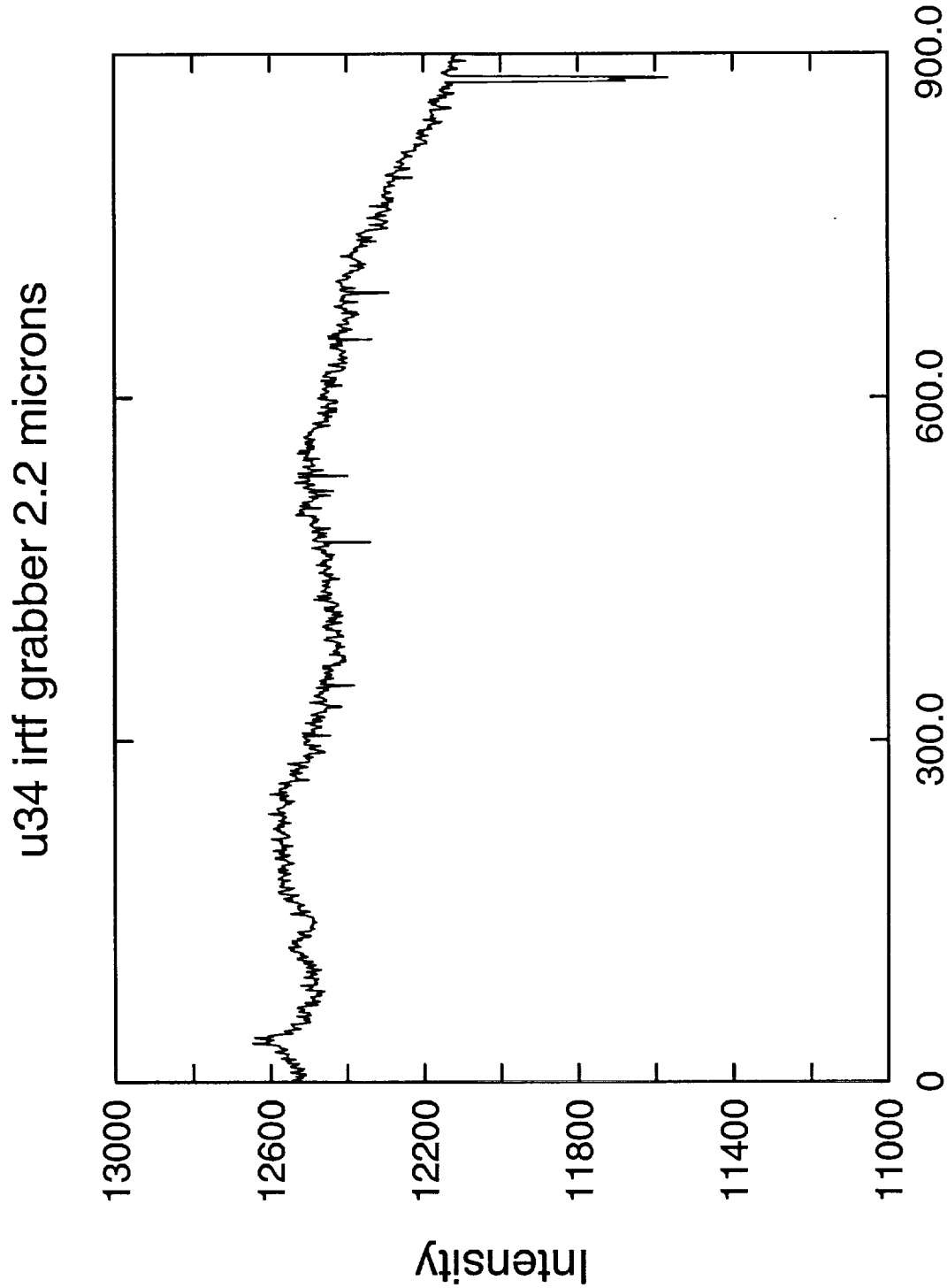

u34 irtf grabber 2.2 microns
Intensity
13000
12600
12200
11800
11400
11000
0
300.0
600.0
900.0
Seconds after 15:45:00.0000 UT

Fig. 3

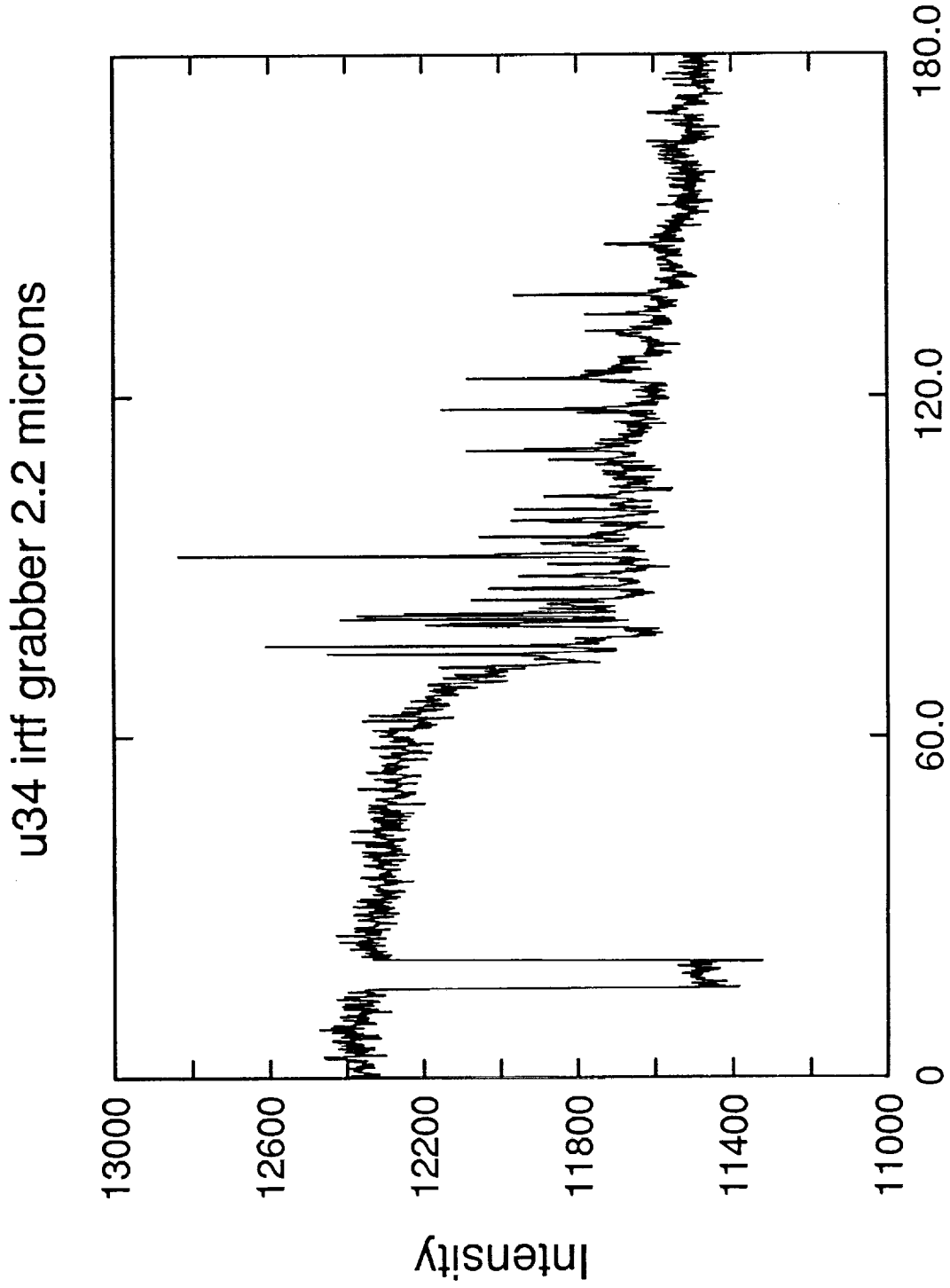

u34 irtf grabber 2.2 microns
Intensity
13000
12600
12200
11800
11400
11000
0
60.0
120.0
180.0
Seconds after 14:41:00.0000 UT

Fig. 4

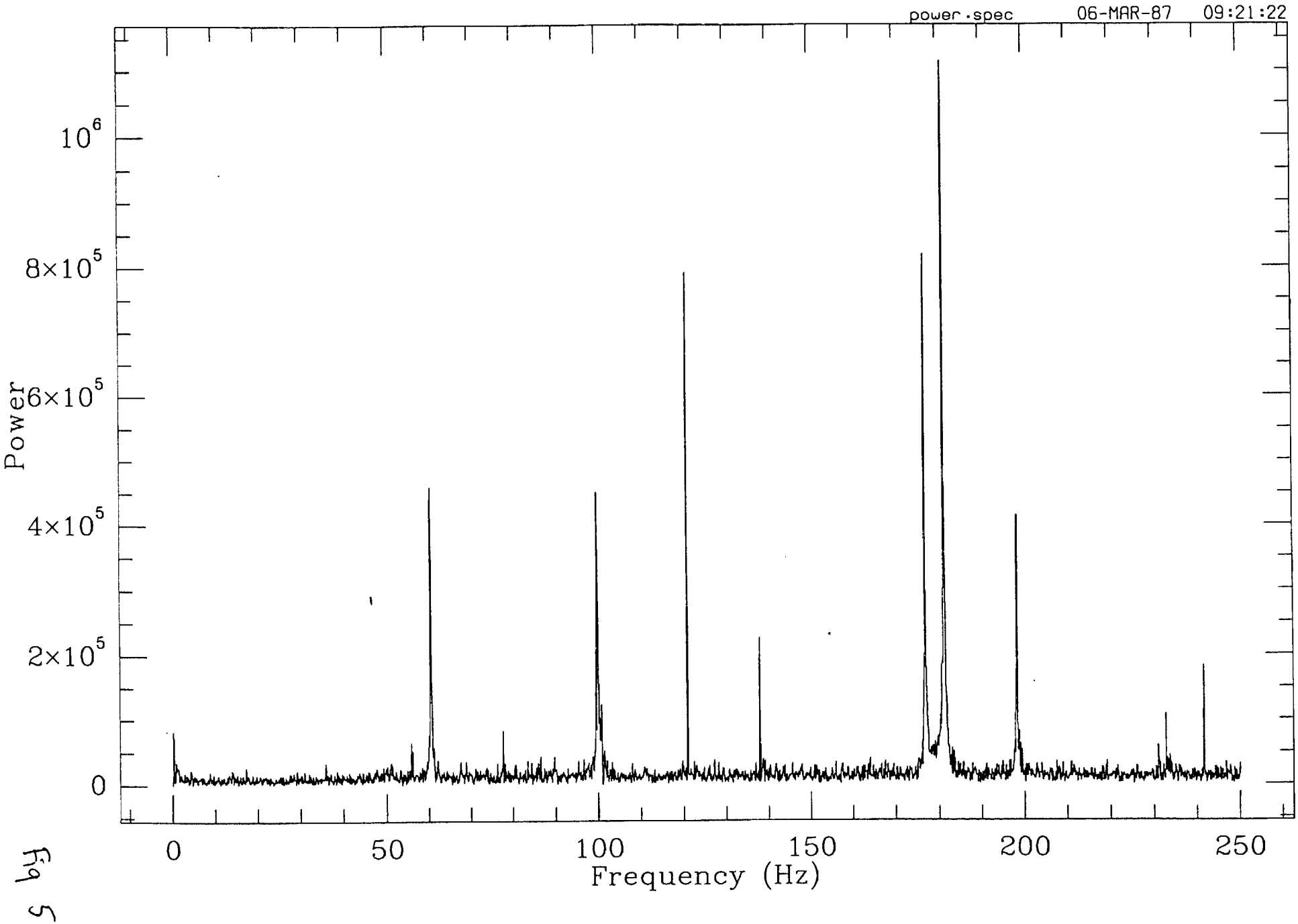

power.spec
06-MAR-87
09:21:22
Power
10^6
8×10^5
6×10^5
4×10^5
2×10^5
0
0
50
100
150
200
250
Frequency (Hz)

Fig 5

08/24/1989 12:57:35
u34irall.gi.sqw

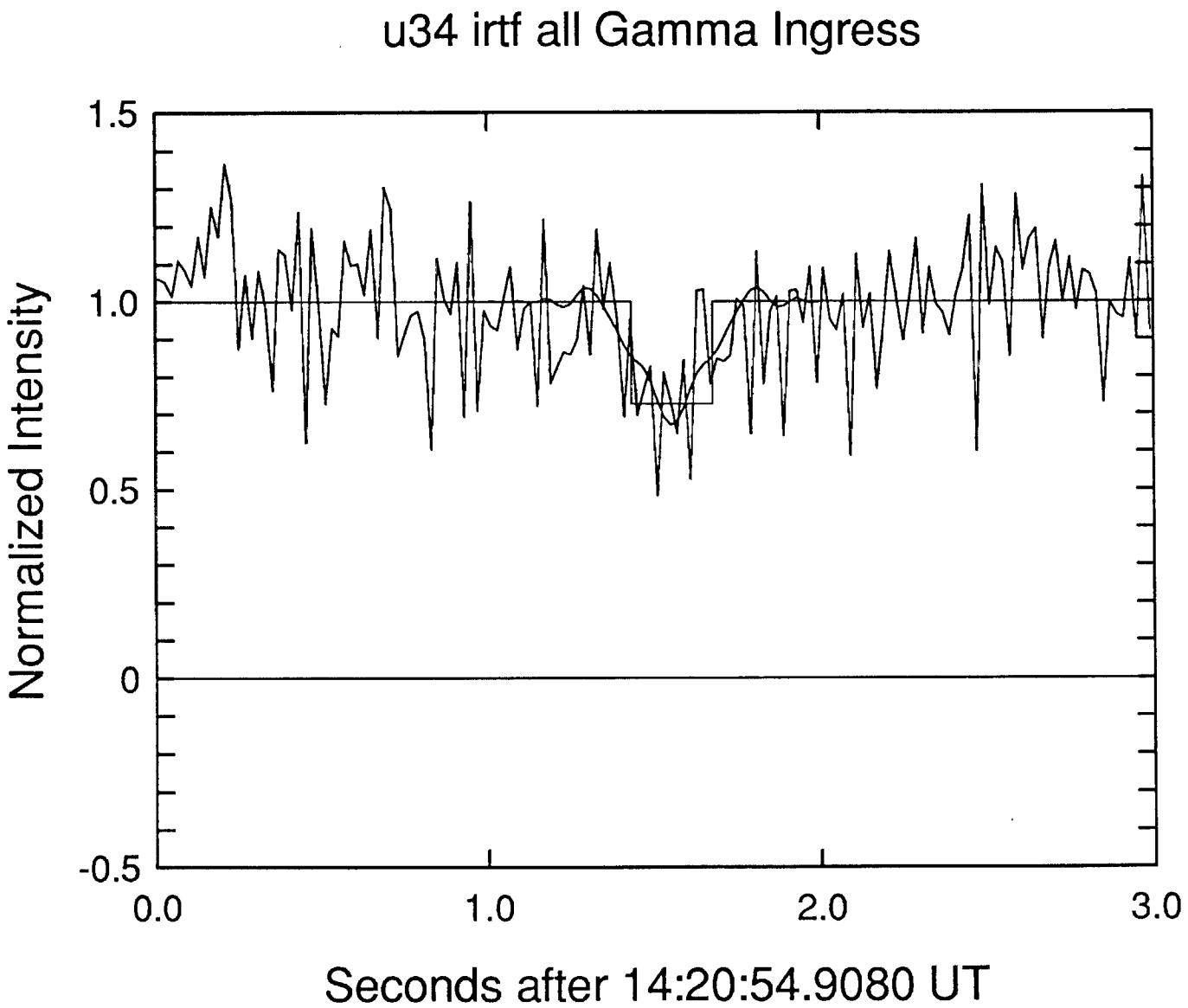


Fig. 6

06/04/1992 17:22:56
U34irall.ee.sqw

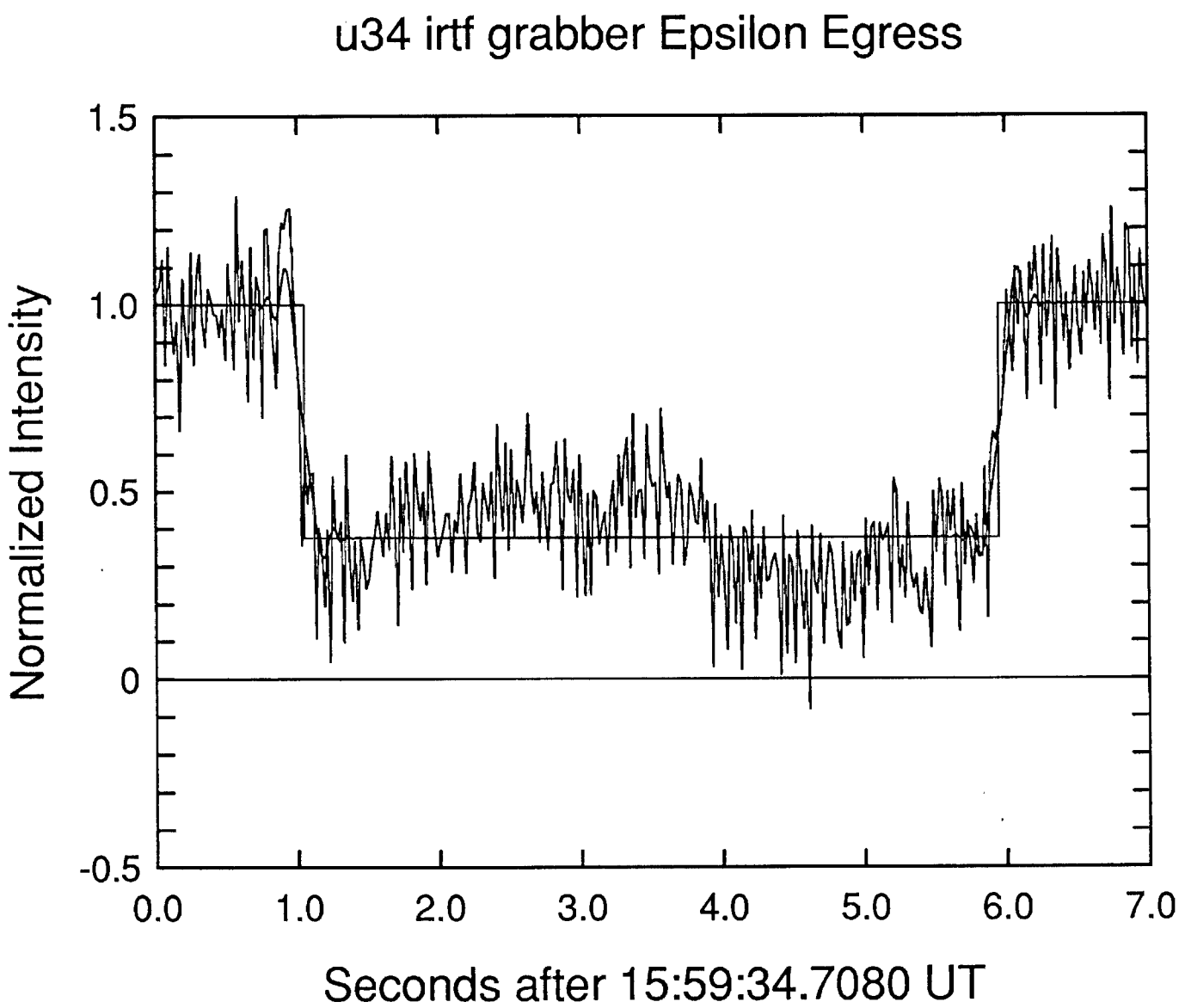


Fig. 7

```
SIMPLE  = F                     / T if standard FITS, F otherwise
BITPIX  = integer               / number of bits per data pixel
CTYPE   = string                / declaration type for C (short, etc.)
NAXIS   = integer               / number of axes (1 for time series)
NAXISn  = integer               / number of data pixels on axis n(base 1)
GROUPS  = T                     / T means that groups are present
GCOUNT  = integer               / # of groups   (channels + other)
PCOUNT  = integer               / # of parameters preceeding a group

FILETYPE= ts                    / ts is time series file
FLTPVERS= 1                     / version number of the filetype
VERSDATE= "1986/08/20"          / date that this version was created
VERSAUTH= jle, rgf, jak         / author(s) of this file version

CLABLn  = string                / label for the implicit axis n
CDSCRn  = string                / description of parameter m: more info than label
CUNITn  = string                / units for the implicit axis n
CDELTn  = double                / increment on implicit axis of 1 pixel
CRPIXn  = double                / index of reference pixel on axis n (zero base)
                                   -0.5 for ref. pixel makes CRVALn + CTIMEn the
                                   "start time" (i.e. when data were turned on)
CRVALn  = double                / added value for axis n reference pixel in CUNITn
CTIMEn  = "hh:mm:ss.sss"        / base time for reference pixel on axis n
CZONEn  = string                / time zone for CTIMEn
CDATEn  = "yyyy/mm/dd"          / base date for reference pixel on axis n
                                  for a time axis: Absolute Time of ref. pixel =
                                  CDATEn + CTIMEn + CRVALn (each in own units)

PLABLm  = string                / label of axis for parameter m
PDSCRm  = string                / description of parameter m: more info than label
PUNITm  = string                / units for parameter m
PZEROm  = double                / zero for parameter m
PSCALm  = double                / scale factor for parameter m
                                  value = scale_factor * pixel + zero

GLABLj  = string                / label of axis for group j
GDSCRj  = string                / description of group j: more info than label
GUNITj  = string                / units for group j
GZEROj  = double                / zero for group j
GSCALj  = double                / scale factor for group j
                                  value = scale_factor * pixel + zero

INSTRj  = string                / instrument used for group j
TLSCPj  = string                / telescope used for group j
OBSVRj  = string                / observer for group j
GSTTMj  = "hh:mm:ss.sss"        / start time of original observations for group j
GZONEj  = string                / time zone for GSTTMj
GSTDTj  = "yyyy/mm/dd"          / date for start time of original observations (j)
GLGTHj  = "hh:mm:ss.sss"        / length of original observation record
GOFILj  = string                / original file containing "data" in group j
GLFILj  = string                / last file containing "data" in group j


LOGINk  = string                / user login id for creation of kth file
COMPk   = string                / computer used for creation of kth file
PTHNMk  = string                / pathname of working directory for kth file
PRGRMk  = string                / name of program that created the kth file
TIMEk   = "hh:mm:ss.sss"        / time for creation of kth file
DATEk   = "yyyy/mm/dd"          / date for creation of kth file

END
```

Fig. 8

```
SIMPLE  = F
BITPIX  = 16
CTYPE   = short
NAXIS   = 1
NAXIS1  = 4800000 / # pts in u34.all.1
GROUPS  = T
GCOUNT  = 1
PCOUNT  = 0
FILETYPE= ts
FLTPVERS= 1
VERSDATE= "1986/08/20"
VERSAUTH= jle, rgf, jak
CLABL1  = time
CDSCR1  = u34 irtf grabber
CUNIT1  = seconds
CDELT1  = 0.002
CRPIX1  = -0.5
CRVAL1  = 0.0
CTIME1  = "14:00:27.688"
CZONE1  = UT
CDATE1  = "1987/02/26"
GLABL1  = 2.2 microns
GUNIT1  = counts per axis unit
GZERO1  = 0.0
GSCAL1  = 1.0
GSTTM1  = "1987/02/26"
GZONE1  = UT
GSTDT1  = "14:00:27.688" / from Marc Buie's letter of 13 March 1987
GLFIL1  = "/usr5/uranus/u34/irtf/raw/u34.all.1"
LOGIN1  = rfrench
COMP1   = thales
PTHNM1  = "/usr5/uranus/u34/irtf/raw/grabber"
PRGRM1  = raw2avg.pro(IDL)
TIME1   = 11:14
DATE1   = "1991/11/22"
END
```

Fig. 9

U34 - 26 February 1987
IRTF Occultation Track

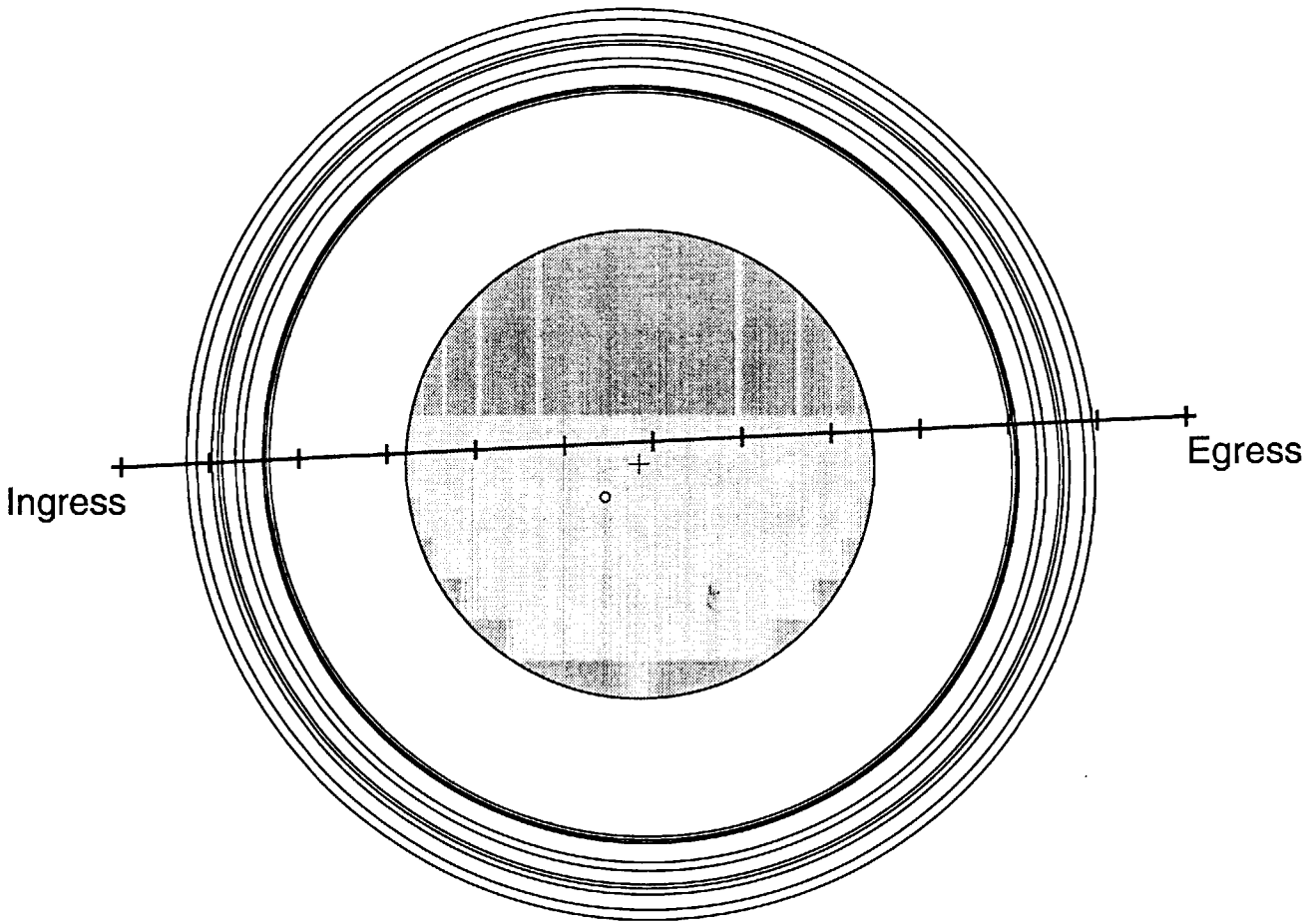
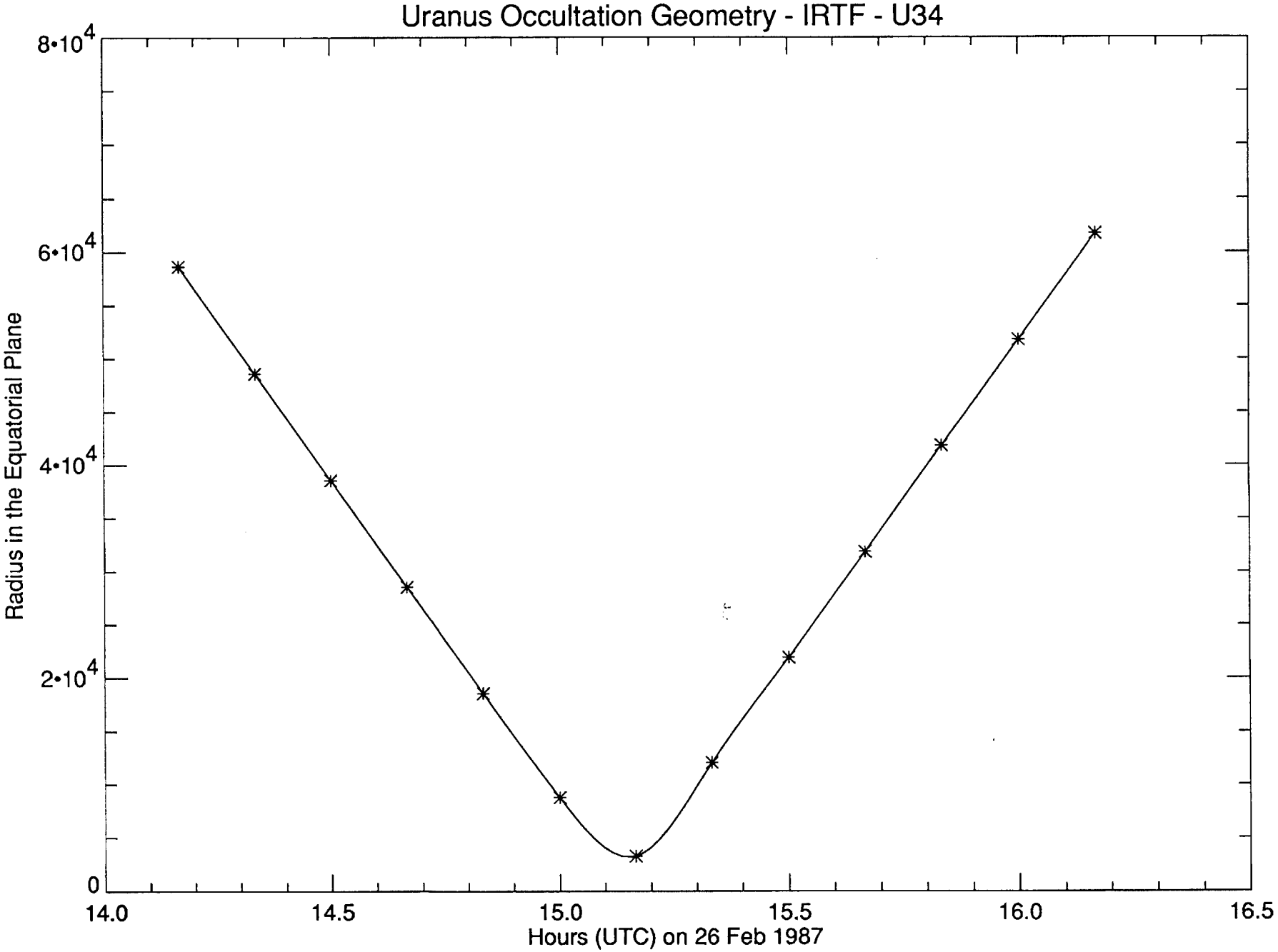
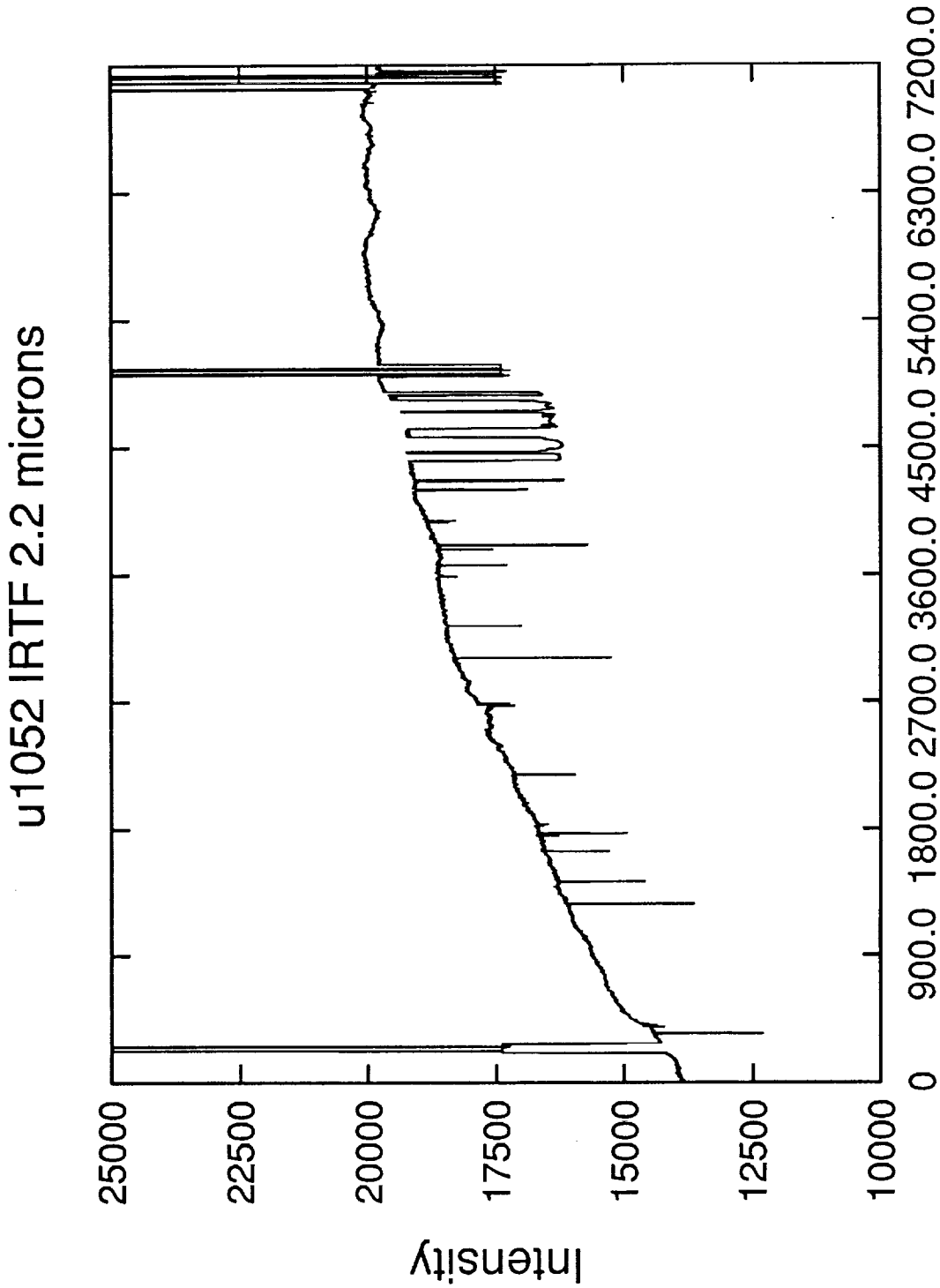


Fig. 10


Uranus Occultation Geometry - IRTF - U34
8•10^4
6•10^4
4•10^4
2•10^4
0
Radius in the Equatorial Plane
14.0
14.5
15.0
15.5
16.0
16.5
Hours (UTC) on 26 Feb 1987

(Fig. 11)



PRECEDING PAGE BLANK NOT FILMED

Fig. 13

```
:
# unpack the tape of 12 May 1988 data from Marc Buie
#
TAPE=/dev/nrmt1h
MAXFILES=4
i=0

while [ $i -lt $MAXFILES ]
do
i=`expr $i + 1`
outfile=FILE$i.data
echo Reading FILE$i and storing data only as $outfile
# skip over the FITS header and swap bytes to form data files
/bin/dd if=$TAPE bs=2880 skip=1 conv=swab of=$outfile
ls -l $outfile
done
echo All Done!
mt -f $TAPE rewoff
```

Fig. 14

```
:
# convert long data files from tape of May 1988 data from Marc Buie
# to ts format. Note that the header file was edited by hand.
# See unpack.sh for commands used to extract FITS data
#       28 November 88 - Dick French (rfrench@kepler)
#       21 January 1989 - revised headers
#       23 January 1989 - revised output file names
#       25 January 1989 - change id number of star
#       25 January 1989 - change id number of star
#       11/21/91 - copied stuff to thales but ran as is

infile1=FILE1.data
outfile1=../ts/u1052irtf.25.ts
header1=FILE1.ts_header

infile2=FILE2.data
outfile2=../ts/u1052irtf.05.ts
header2=FILE2.ts_header

infile3=FILE3.data
outfile3=../ts/u1052irtf.01.ts
header3=FILE3.ts_header

infile4=FILE4.data
outfile4=../ts/u1052irtf.002.ts
header4=FILE4.ts_header

echo -n Creating $outfile1 ...
cat $header1 $infile1 > $outfile1
echo
ls -l $outfile1

echo -n Creating $outfile2 ...
cat $header2 $infile2 > $outfile2
echo
ls -l $outfile2

echo -n Creating $outfile3 ...
cat $header3 $infile3 > $outfile3
echo
ls -l $outfile3

echo -n Creating $outfile4 ...
cat $header4 $infile4 > $outfile4
echo
ls -l $outfile4

echo All Done!
```

Fig. 15

```
SIMPLE  = F                     / T if standard FITS, F otherwise
BITPIX  = 16                    / number of bits per data pixel
CTYPE   = short                 / declaration type for C (short, etc.)
NAXIS   = 1                     / number of axes (1 for time series)
NAXIS1  = 3600000               / number of data pixels on axis n(base 1)
GROUPS  = T                     / T means that groups are present
GCOUNT  = 1                     / # of groups   (channels + other)
PCOUNT  = 0                     / # of parameters preceeding a group
FILETYPE= ts                    / ts is time series file
FLTPVERS= 1                     / version number of the filetype
VERSDATE= "1986/08/20"          / date that this version was created
VERSAUTH= jle, rgf, jak         / author(s) of this file version
CLABL1  = time                  / label for the implicit axis n
CDSCR1  = u1052 IRTF            / description of parameter m: more info than label
CUNIT1  = seconds               / units for the implicit axis n
CDELT1  = 0.0020                / increment on implicit axis of 1 pixel
CRPIX1  = -0.5                  / index of reference pixel on axis n (zero base)
CRVAL1  = 0.0                   / added value for axis n reference pixel in CUNITn
CTIME1  = "13:00:00.016"        / base time for reference pixel on axis n
CZONE1  = UT                    / time zone for CTIMEn
CDATE1  = "1988/05/12"          / base date for reference pixel on axis n
GLABL1  = 2.2 microns           / label of axis for group j
GUNIT1  = counts per axis unit/ units for group j
GZERO1  = 0.0                   / zero for group j
GSCAL1  = 1.0                   / scale factor for group j
TLSCP1  = IRTF                  / telescope used for group j
OBSVR1  = Marc Buie             / observer for group j
GSTTM1  = "13:00:00.016"        / start time of original observations for group j
GZONE1  = UT                    / time zone for GSTTMj
GSTDT1  = "1988/05/12"          / date for start time of original observations (j)
GLGTH1  = "02:00:00.000"        / length of original observation record
GOFIL1  = FILE4.data            / original file containing "data" in group j
GLFIL1  = FILE4.data            / last file containing "data" in group j
LOGIN1  = rfrench               / user login id for creation of kth file
COMP1   = kepler                / computer used for creation of kth file
PTHNM1  = "/usr1/uranus/u46/mko/raw" / working directory for kth file
PRGRM1  = dd and unpack.sh      / name of program that created the kth file
TIME1   = "18:23:00"            / time for creation of kth file
DATE1   = "1989/01/21"          / date for creation of kth file
END
```

Fig. 16

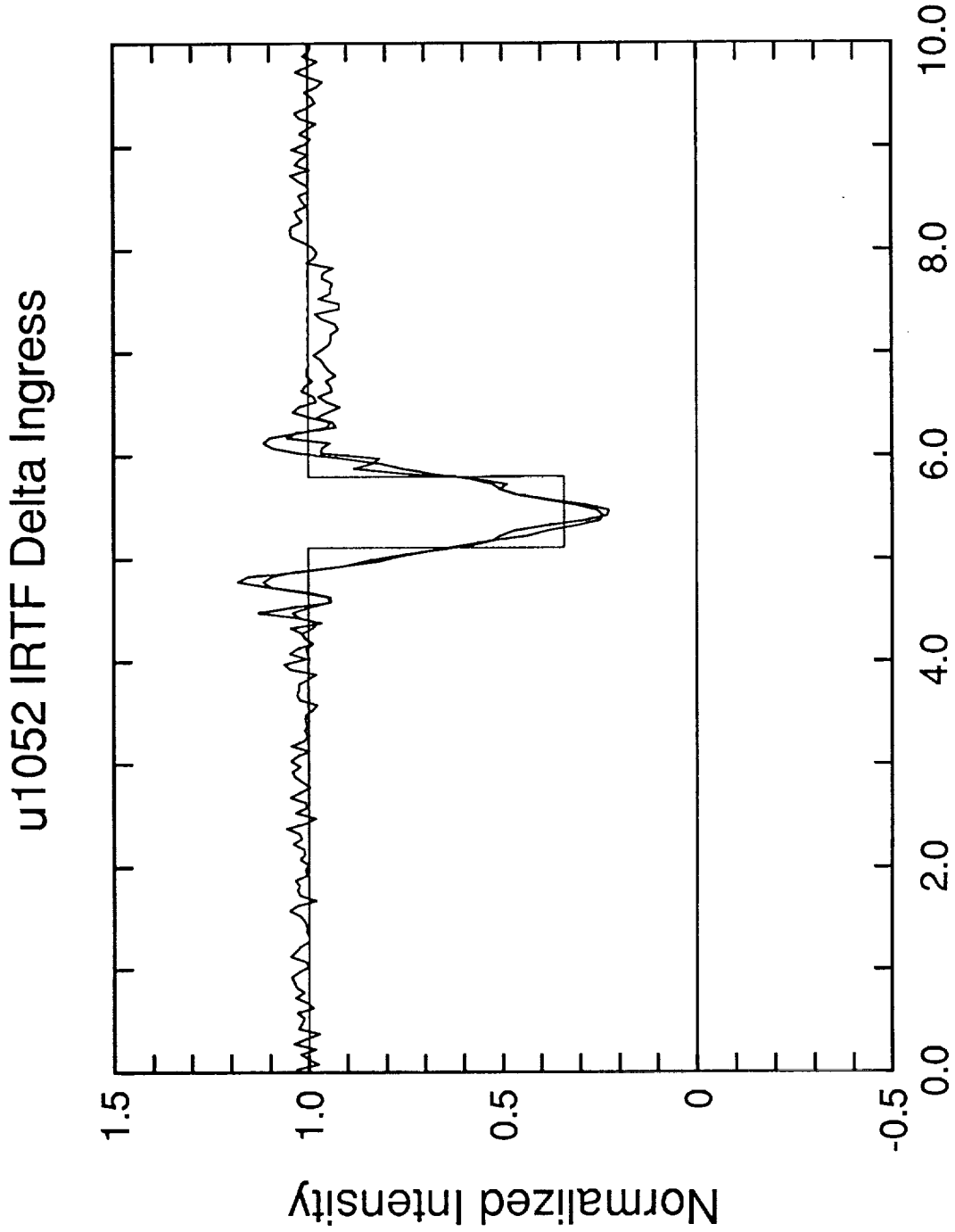

03/10/1989 17:08:57
u1052irtf_di.sqw
u1052 IRTF Delta Ingress
Normalized Intensity
1.5
1.0
0.5
0
-0.5
0.0
2.0
4.0
6.0
8.0
10.0
Seconds after 13:27:16.0160 UT

Fig. 17

03/10/1989 17:07:56
u1052irtf_de.sqw

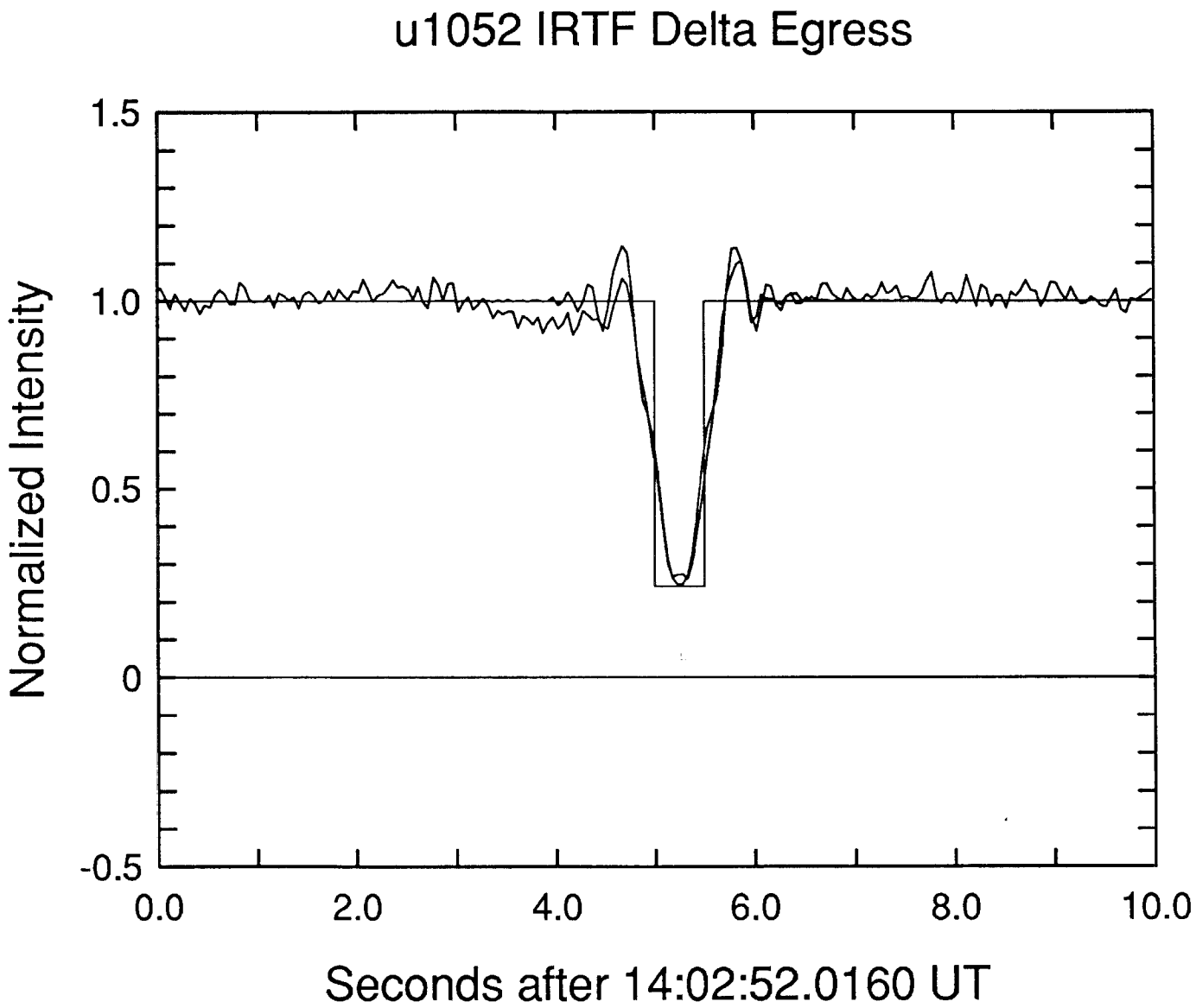


Fig. 18

Table I

Results of Square-Well Ring Profile Fits to 12 May 1988 Observations of u1052 IRTF								
Ring	Event	Midtime (UTC)	Width (km)	Equivalent Width E (km)	Equivalent Depth A (km)	Fractional Transmission f_0	Normal Optical Depth	True Anomaly (deg)
β	I	13:36:22.873 ± 0.014	7.24 ± 0.08	3.10 ± 0.08	4.09 ± 0.15	0.56 ± 0.01	[0.57]	?.?
β	E	13:53:54.449 ± 0.007	5.70 ± 0.06	2.87 ± 0.08	4.07 ± 0.16	0.48 ± 0.01	[0.71]	?.?
η	I	13:30:32.873 ± 0.007	2.11 ± 0.09	0.68 ± 0.03	0.82 ± 0.04	0.67 ± 0.02	[0.39]	?.?
η	E	13:59:46.292 ± 0.012	3.09 ± 0.15	0.65 ± 0.03	0.74 ± 0.04	0.78 ± 0.01	[0.24]	?.?
γ	I	13:29:09.889 ± 0.002	1.45 ± 0.05	1.39 ± 0.03	7.76 ± 2.76	0.004 ± 0.02	[5.36]	?.?
γ	E	14:01:08.650 ± 0.004	3.54 ± 0.08	3.15 ± 0.06	8.69 ± 1.12	0.08 ± 0.03	[2.45]	?.?
δ	I	13:27:21.468 ± 0.005	4.38 ± 0.07	2.79 ± 0.08	4.55 ± 0.24	0.34 ± 0.02	[1.03]	?.?
δ	E	14:02:57.261 ± 0.005	3.18 ± 0.12	2.33 ± 0.06	4.37 ± 0.35	0.24 ± 0.04	[1.37]	?.?
ε	I	13:21:06.402 ± 0.006	46.64 ± 0.07	39.01 ± 0.81	90.70 ± 6.22	0.13 ± 0.02	[1.94]	?.?
ε	E	14:09:59.633 ± 0.006	82.46 ± 0.09	55.24 ± 1.34	94.27 ± 4.47	0.31 ± 0.02	[1.14]	?.?

Notes:
1) I and E stand for ingress and egress, respectively.
2) Numbers in square brackets were derived from other parameters in the fit.

Fig. 19

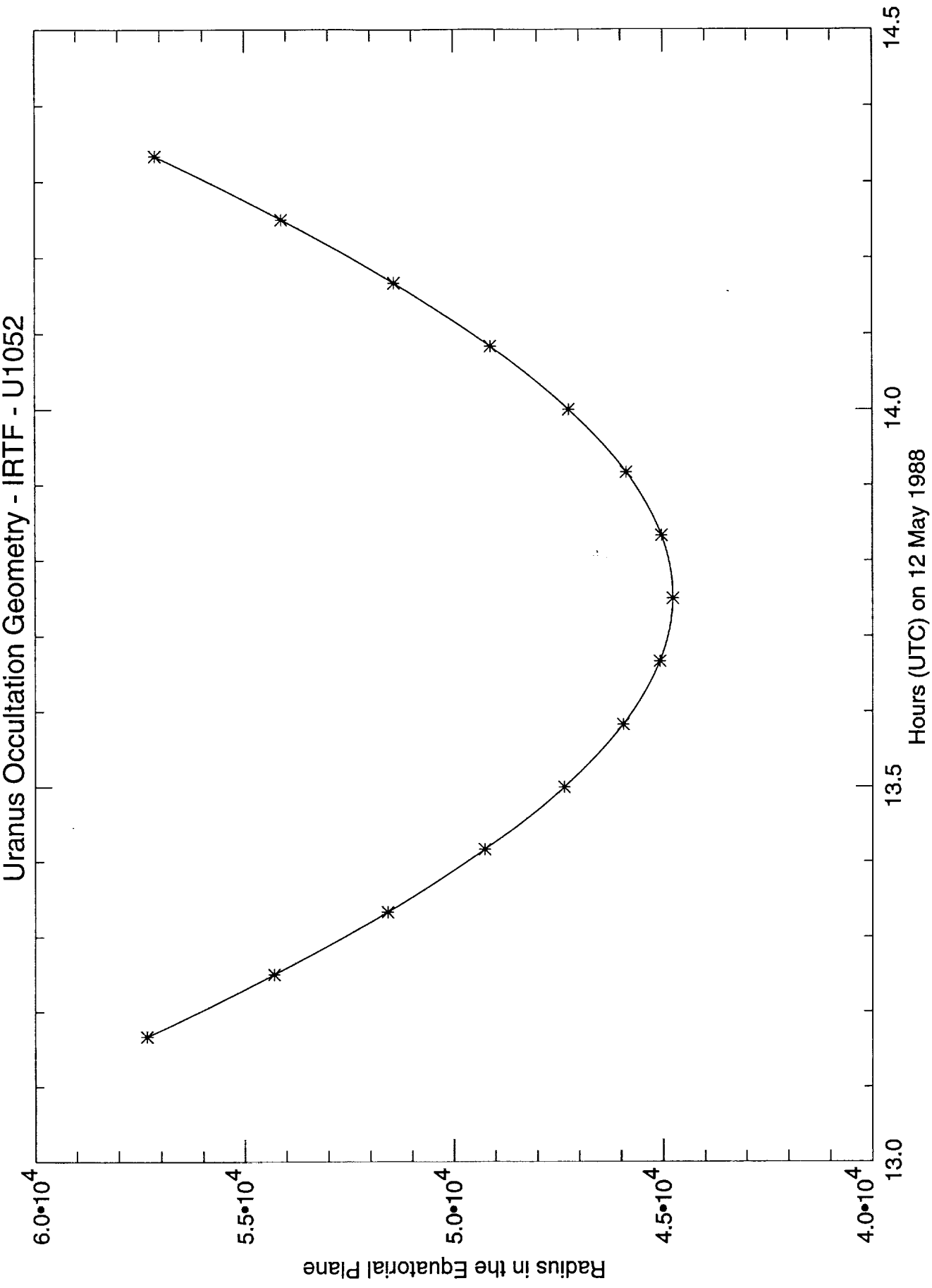

Uranus Occultation Geometry - IRTF - U1052
Radius in the Equatorial Plane
6.0•10^4
5.5•10^4
5.0•10^4
4.5•10^4
4.0•10^4
13.0
13.5
14.0
14.5
Hours (UTC) on 12 May 1988

Fig. 20

U65 - 21 June 1990
IRTF Occultation Track

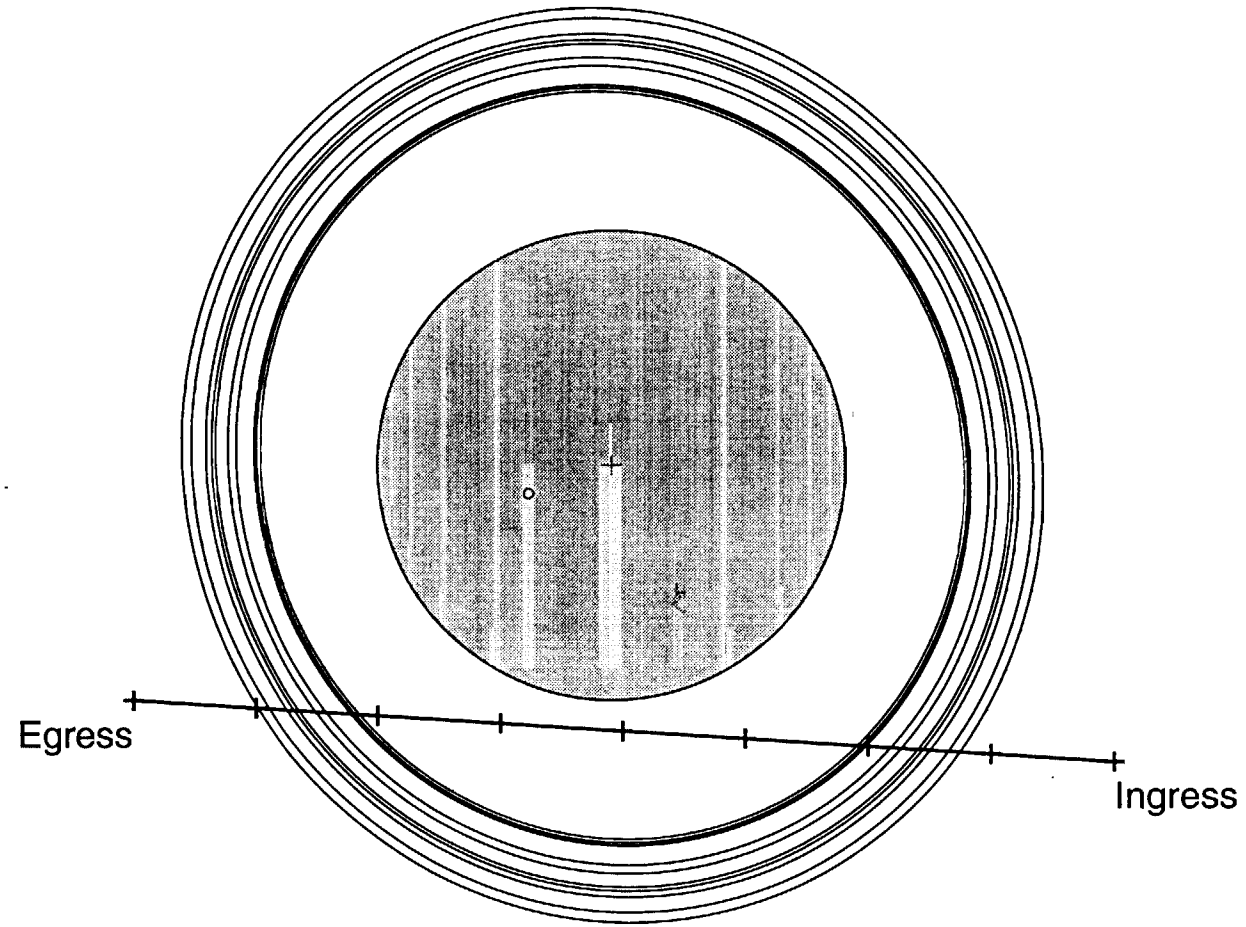


Fig. 21

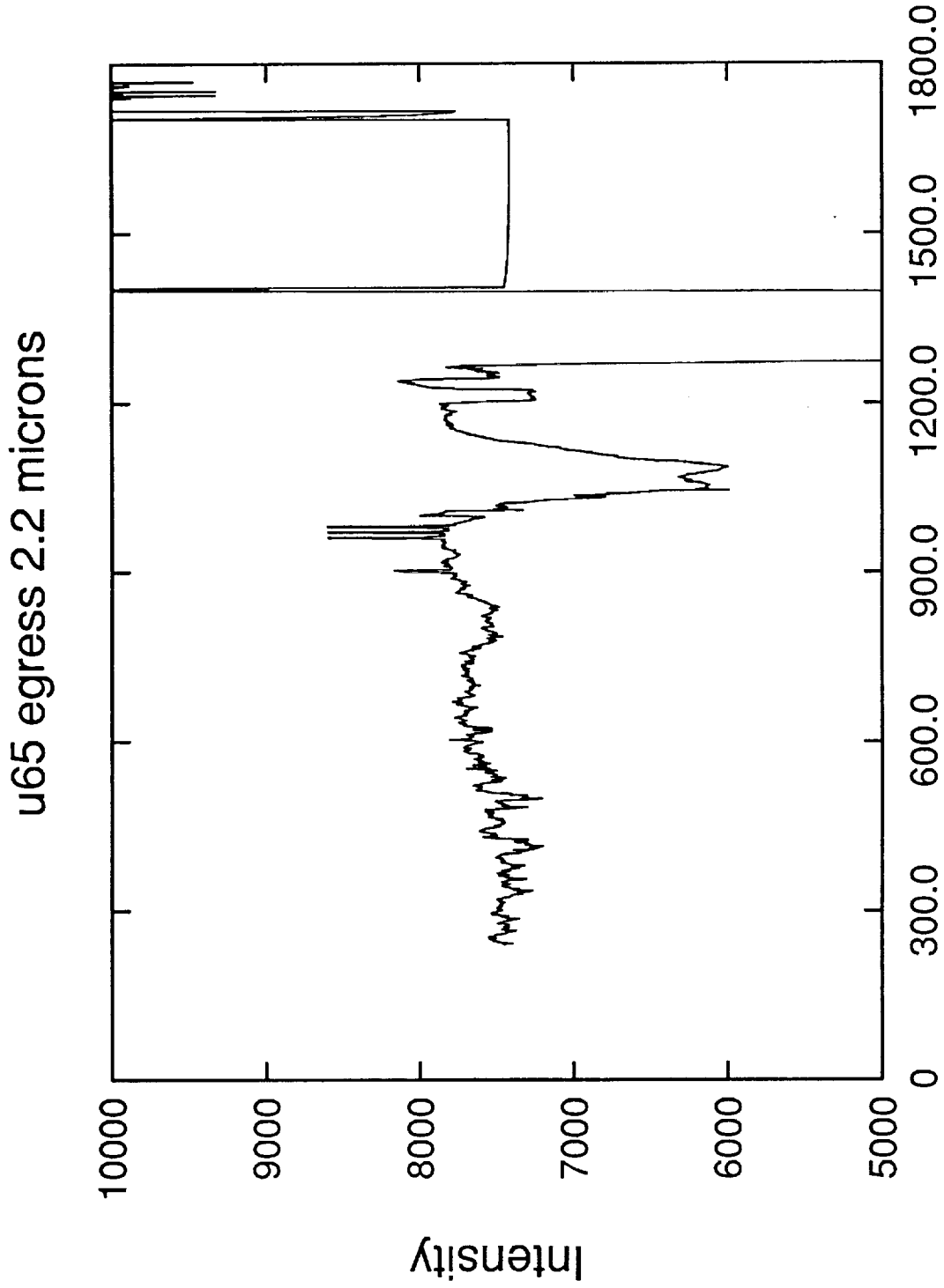


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Fig. 23

```
SIMPLE  = F
BITPIX  = 16
CTYPE   = short
NAXIS   = 1
NAXIS1  = 1916000
GROUPS  = T
GCOUNT  = 1
PCOUNT  = 0
FILETYPE= ts
FLTPVERS= 1
VERSDATE= "1986/08/20"
VERSAUTH= jle, rgf, jak
CLABL1  = time
CDSCR1  = u65 ingress
CUNIT1  = seconds
CDELT1  = 0.002
CRPIX1  = -0.5
CRVAL1  = 0.0
CTIME1  = "10:00:00.299"
CZONE1  = UT
CDATE1  = "1990/06/20"
GLABL1  = 2.2 microns
GUNIT1  = counts per axis unit
GZERO1  = 0.0
GSCAL1  = 1.0
GSTTM1  = "1990/06/20"
GZONE1  = UT
GSTDT1  = "10:00:00.299"
GLFIL1  = "/usr1/tmp/u65/u65irt2f3.ts.hdr"
LOGIN1  = mclark
COMP1   = thales
PTHNM1  = "/usr1/tmp/u65/ts"
PRGRM1  = grabber2dat.pro
TIME1   = 15:35
DATE1   = "1990/08/17"
END
```

Fig. 24

```
SIMPLE  = F
BITPIX  = 16
CTYPE   = short
NAXIS   = 1
NAXIS1  = 780000
GROUPS  = T
GCOUNT  = 1
PCOUNT  = 0
FILETYPE= ts
FLTPVERS= 1
VERSDATE= "1986/08/20"
VERSAUTH= jle, rgf, jak
CLABL1  = time
CDSCR1  = u65 egress
CUNIT1  = seconds
CDELT1  = 0.002
CRPIX1  = -0.5
CRVAL1  = 0.0
CTIME1  = "11:04:00.299"
CZONE1  = UT
CDATE1  = "1990/06/20"
GLABL1  = 2.2 microns
GUNIT1  = counts per axis unit
GZERO1  = 0.0
GSCAL1  = 1.0
GSTTM1  = "1990/06/20"
GZONE1  = UT
GSTDT1  = "11:04:00.299"
GLFIL1  = "/usr1/tmp/u65/u65irt2f4.ts.hdr"
LOGIN1  = mclark
COMP1   = thales
PTHNM1  = "/usr1/tmp/u65/ts"
PRGRM1  = grabber2dat.pro
TIME1   = 17:15
DATE1   = "1990/08/17"
END
```

Figr 25

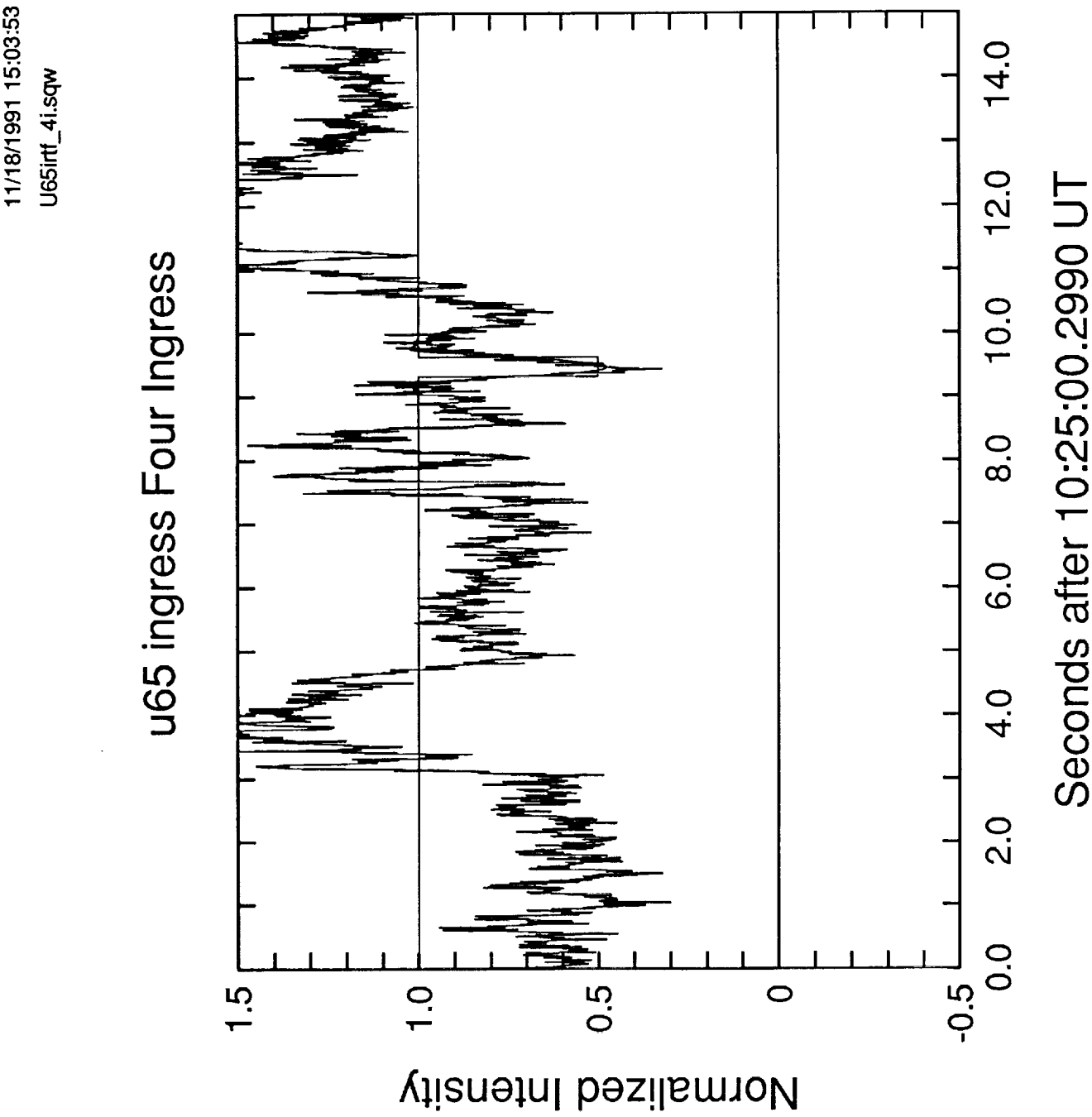

11/18/1991 15:03:53
U65irtf_4i.sqw
u65 ingress Four Ingress
Normalized Intensity
1.5
1.0
0.5
0
-0.5
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
Seconds after 10:25:00.2990 UT

Fig. 26

11/21/1991 10:42:09
U65irtf_4e.sqw

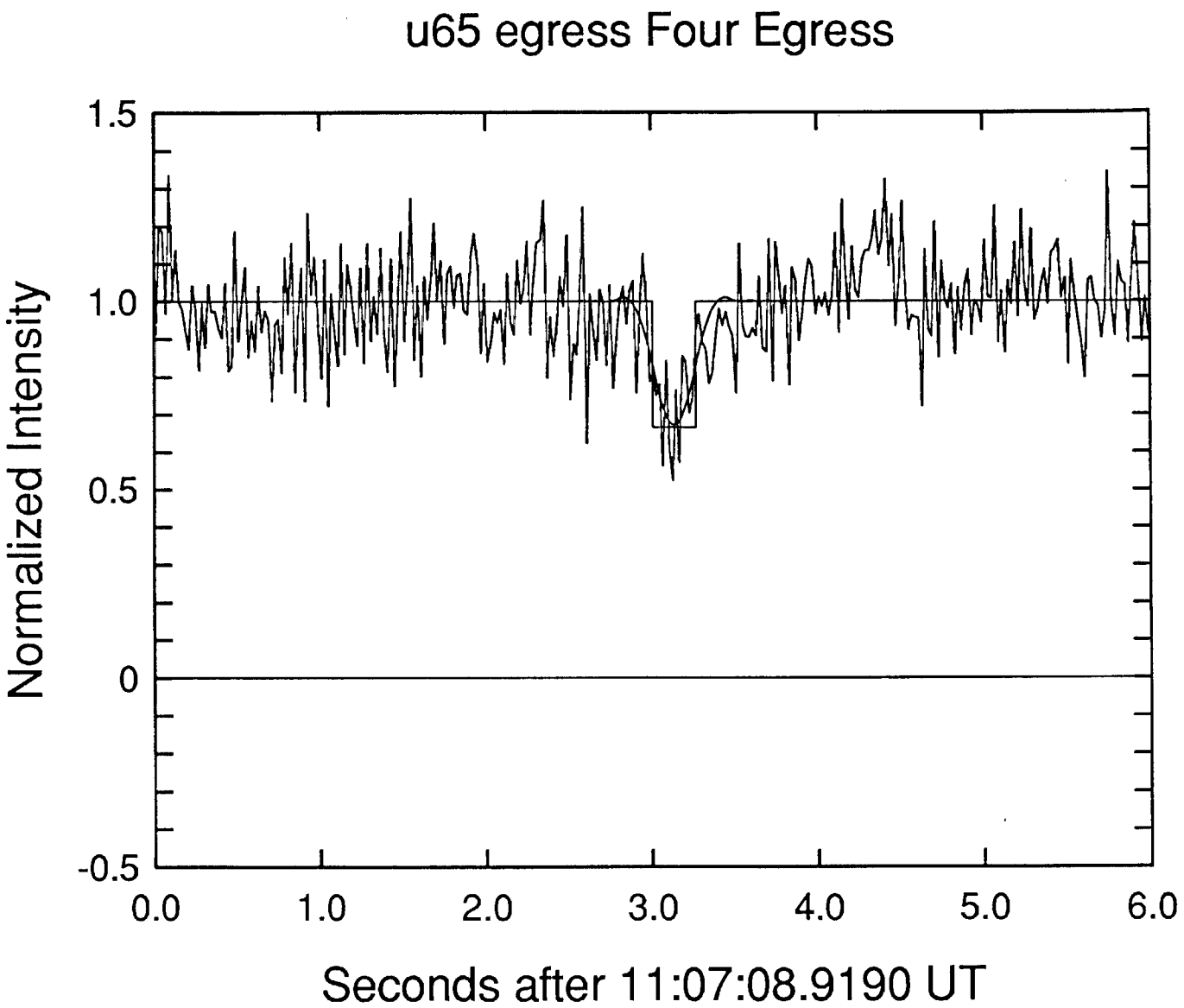


Fig 2a

11/19/1991 11:50:45
U65irtf_ae.sqw

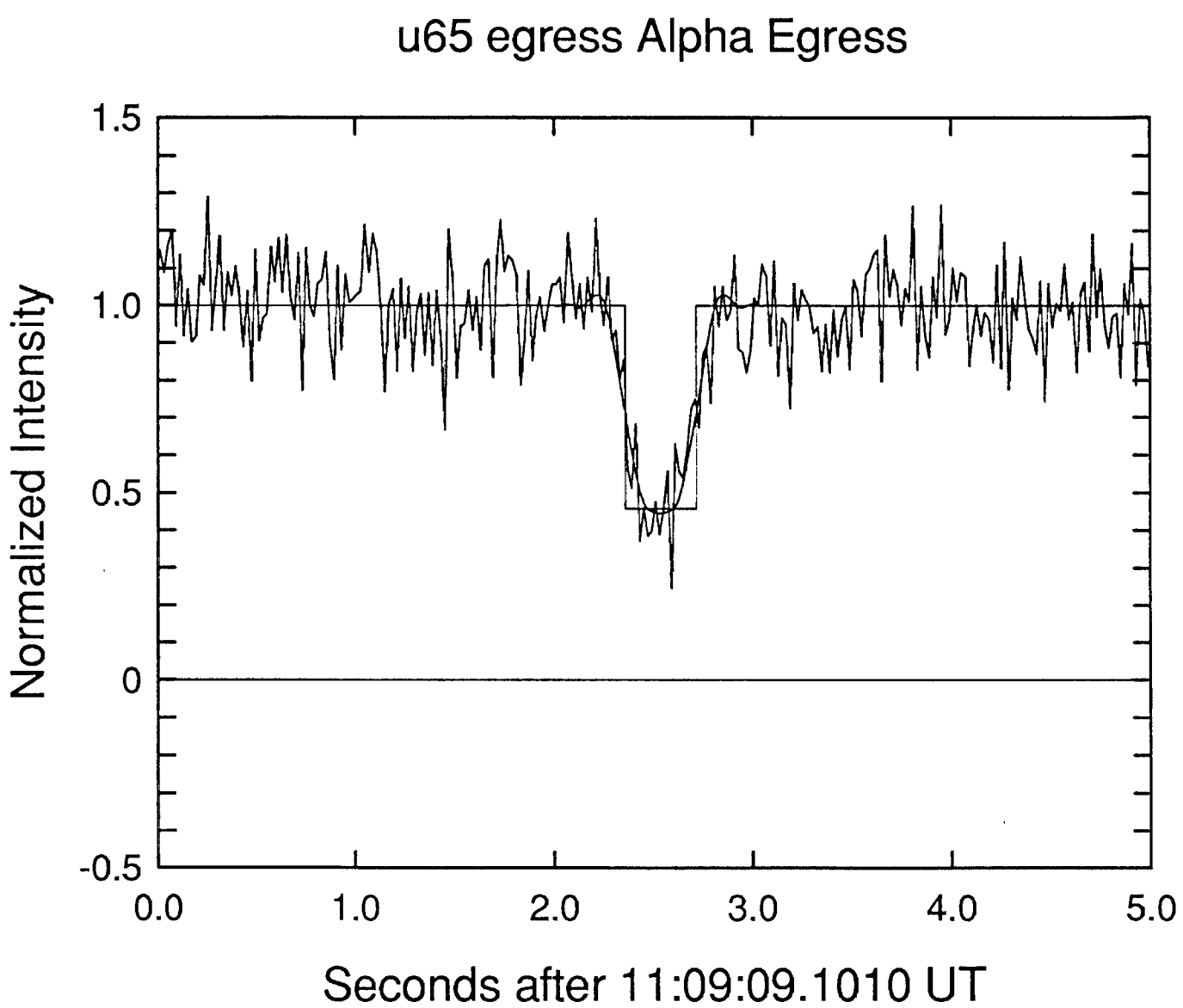
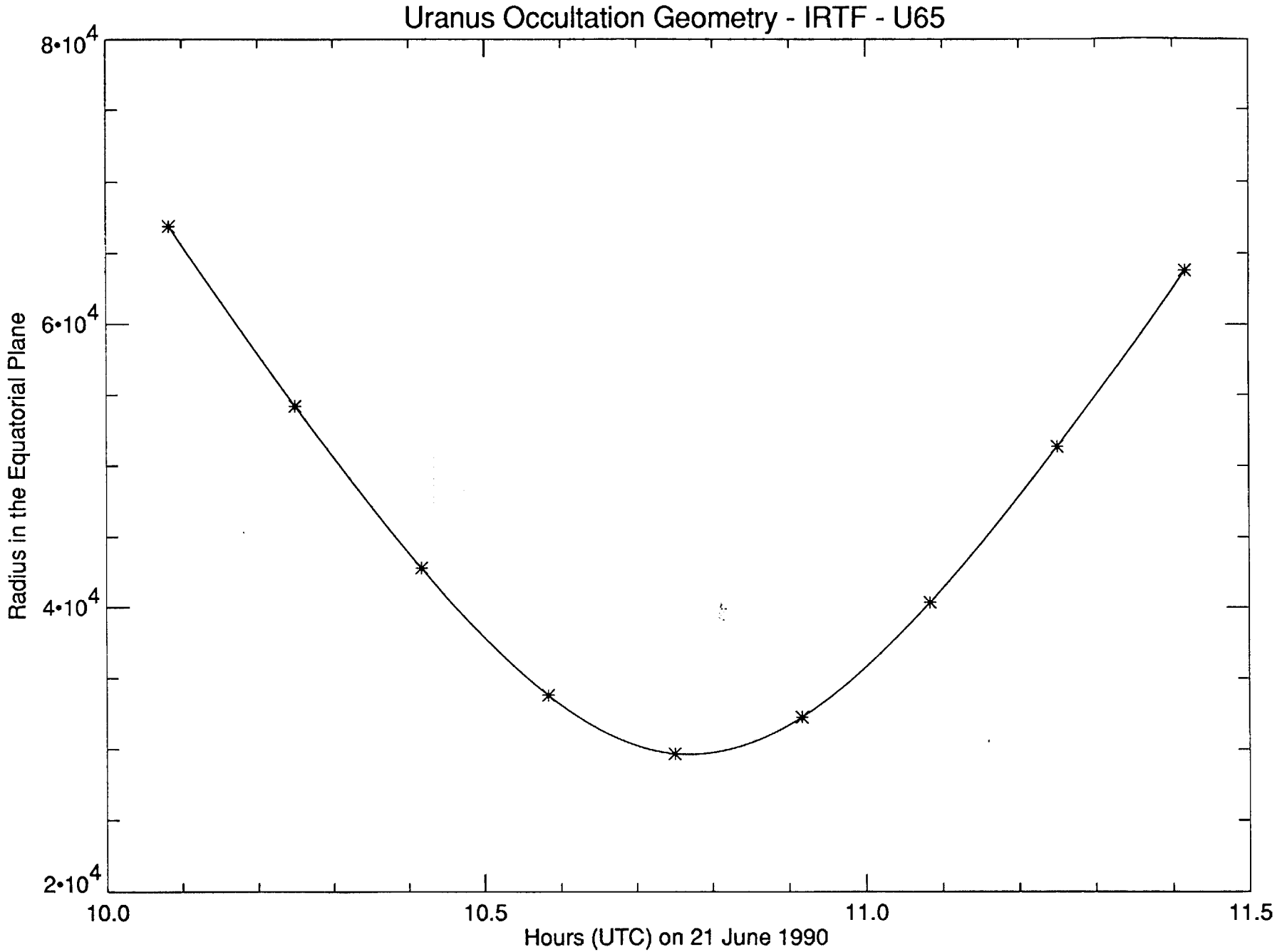


Fig. 28


Uranus Occultation Geometry - IRTF - U65
8•10^4
6•10^4
4•10^4
2•10^4
Radius in the Equatorial Plane
10.0
10.5
11.0
11.5
Hours (UTC) on 21 June 1990

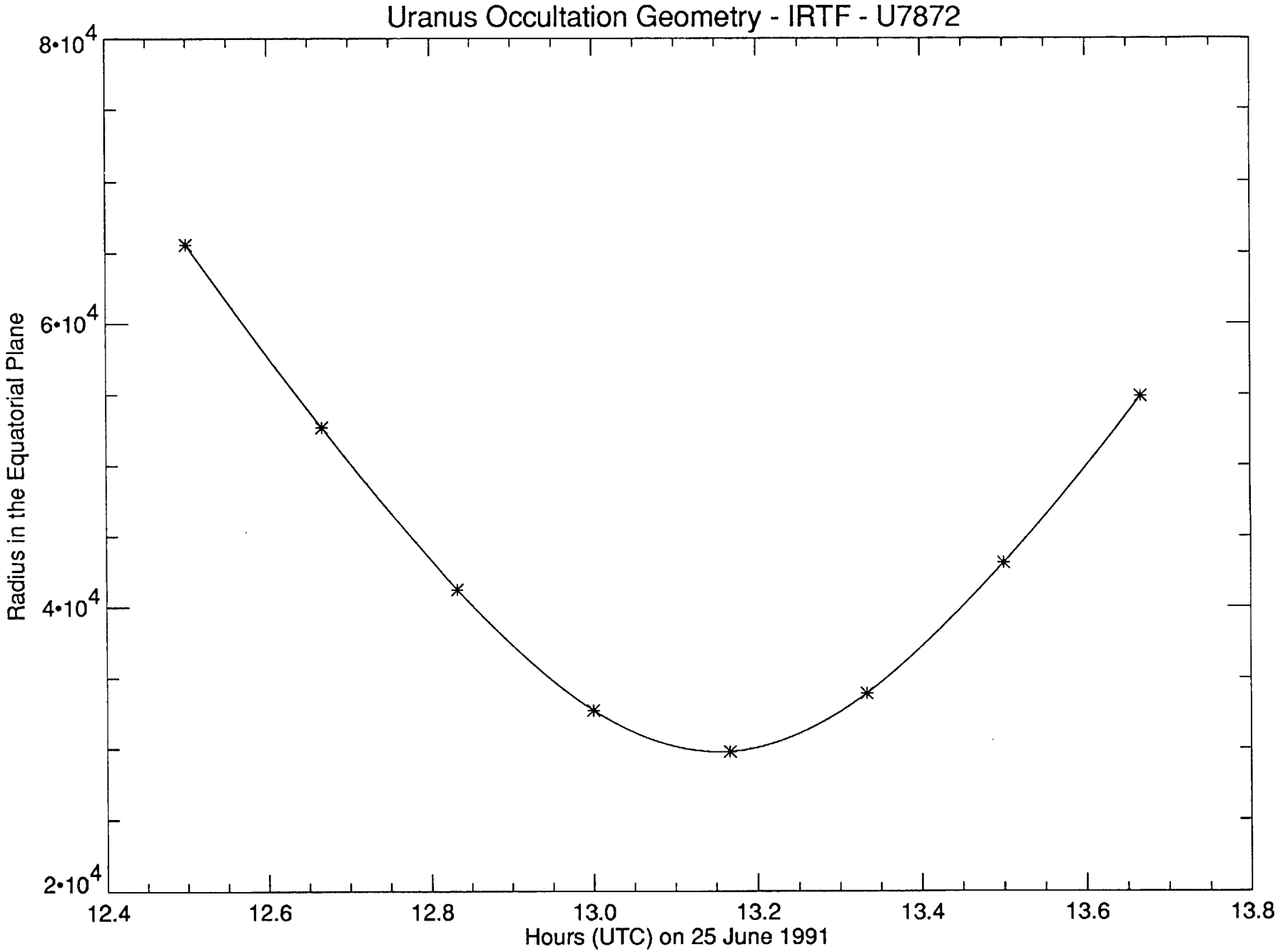


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Fig 31

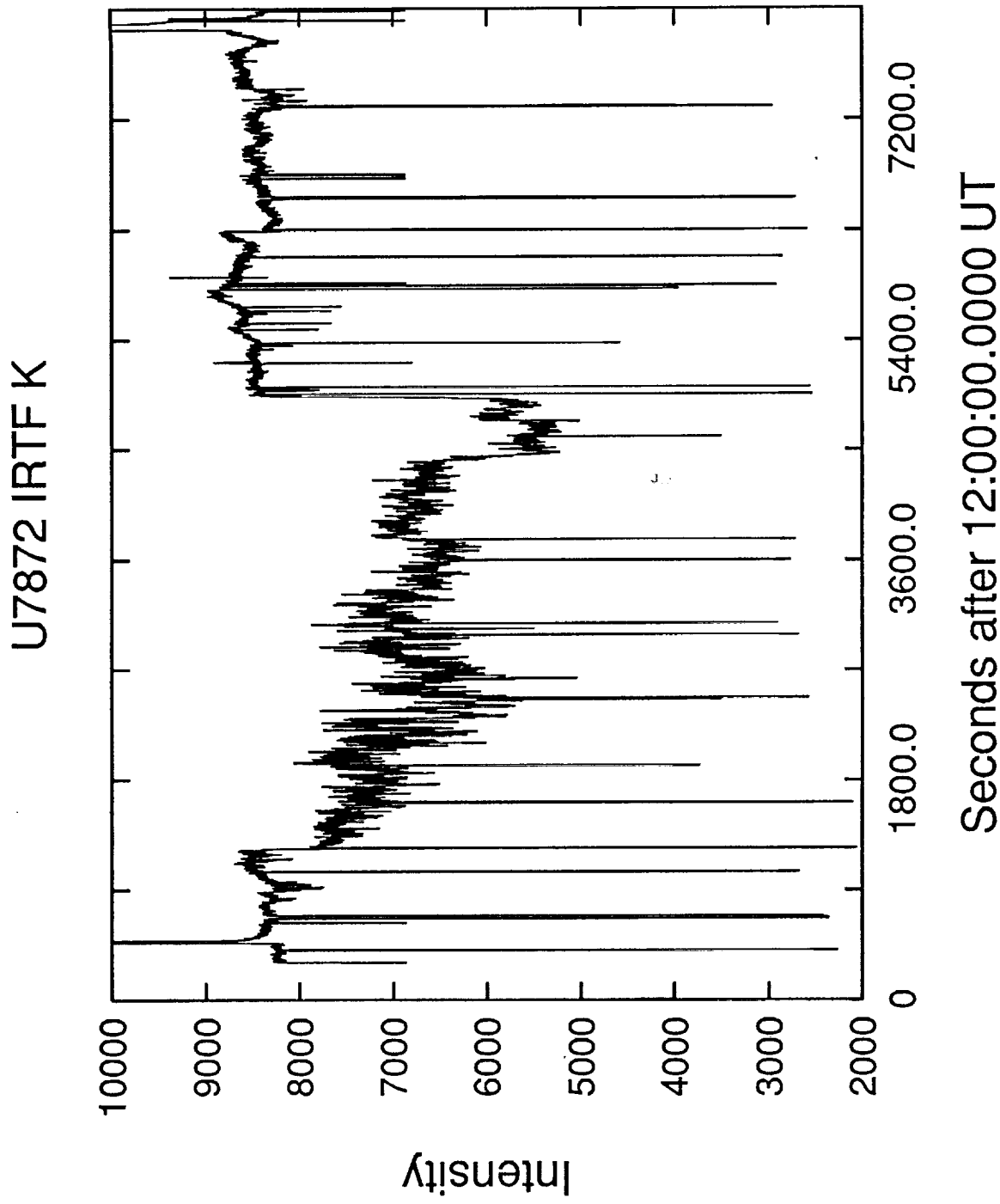
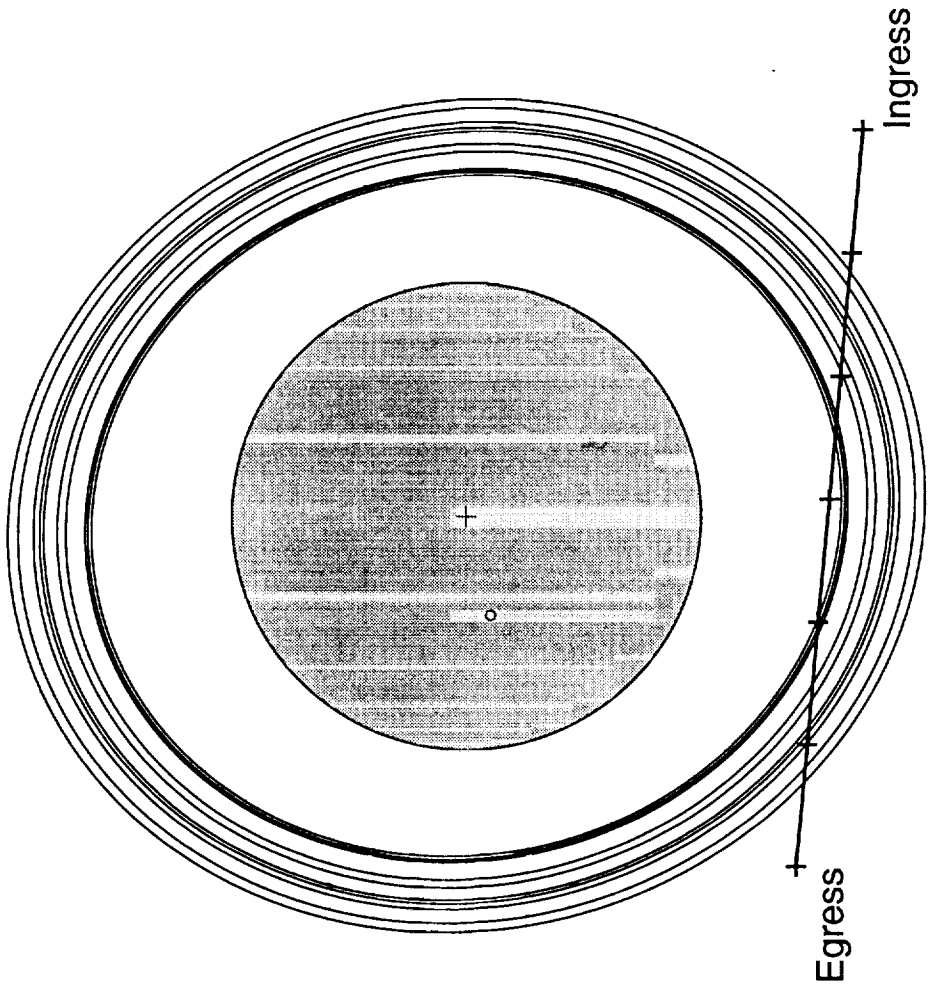

U7872 IRTF K
Intensity
10000
9000
8000
7000
6000
5000
4000
3000
2000
0
1800.0
3600.0
5400.0
7200.0
Seconds after 12:00:00.0000 UT

Fig. 32

U7808 - 28 June 1991
IRTF Occultation Track



33,34.

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Fig. 35

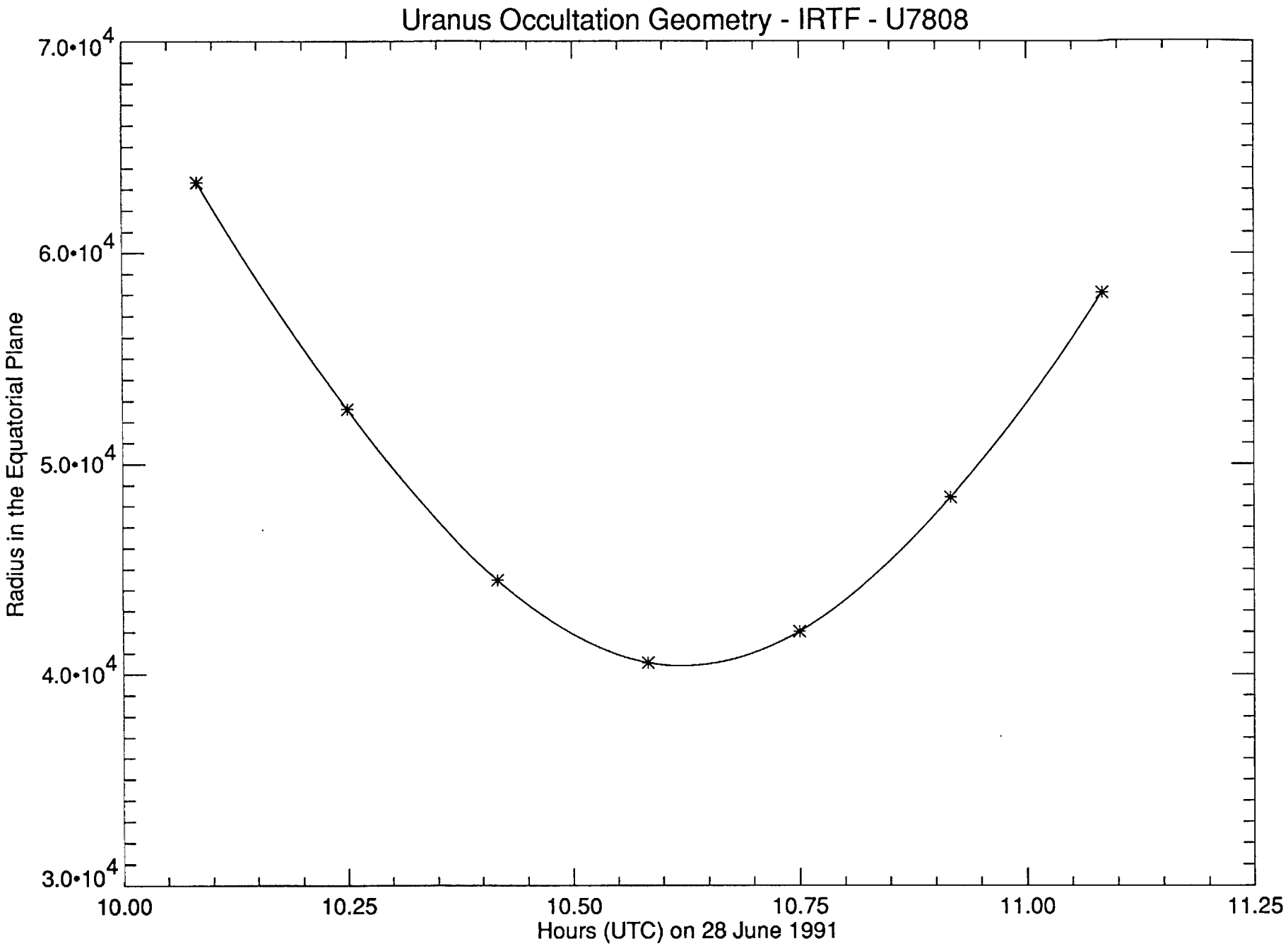
Uranus Occultation Geometry - IRTF - U7808
7.0•10^4
6.0•10^4
5.0•10^4
4.0•10^4
3.0•10^4
Radius in the Equatorial Plane
10.00
10.25
10.50
10.75
11.00
11.25
Hours (UTC) on 28 June 1991

Fig. 2b

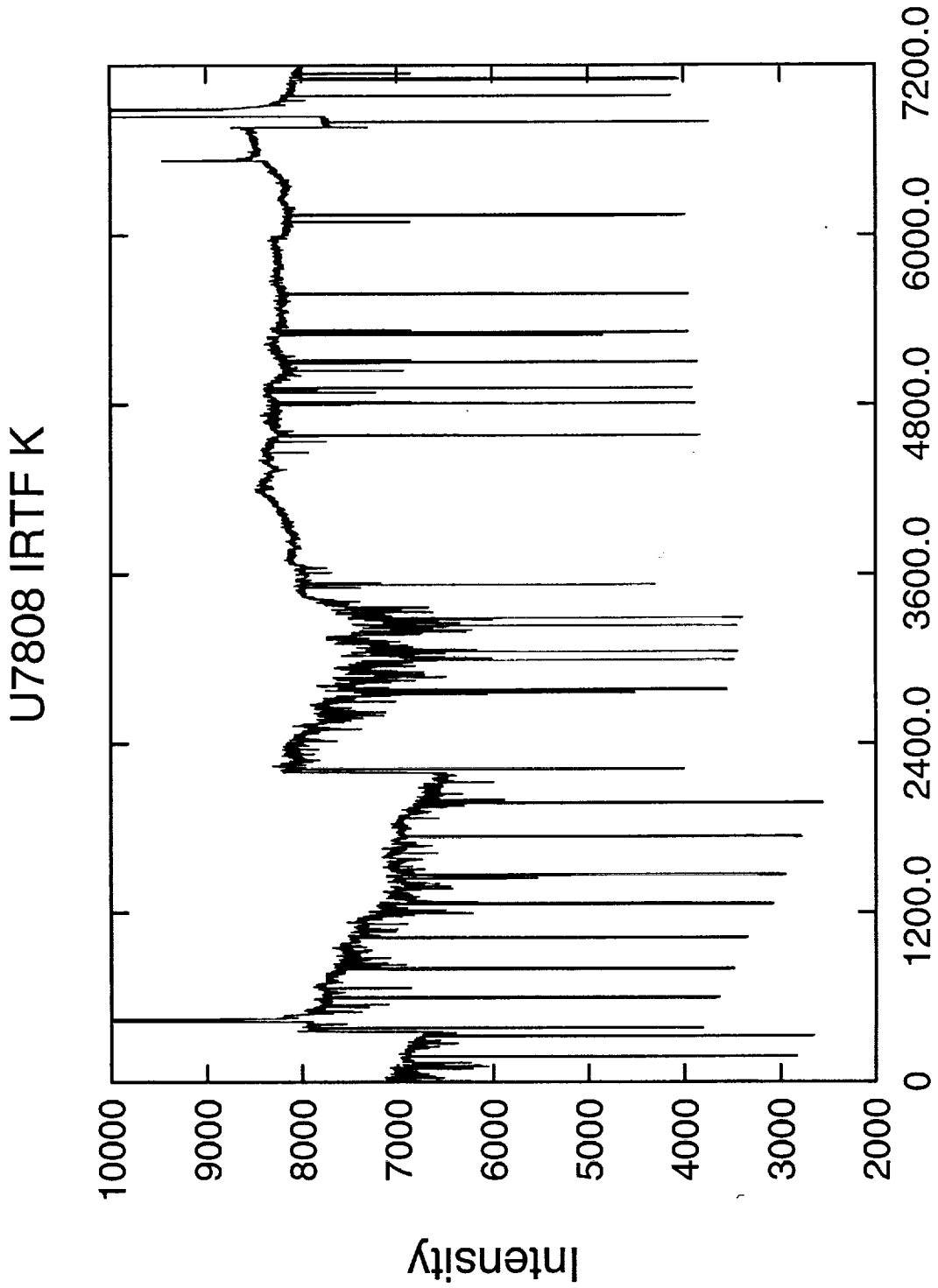
U7808 IRTF K
Intensity
10000
9000
8000
7000
6000
5000
4000
3000
2000
0
1200.0
2400.0
3600.0
4800.0
6000.0
7200.0
Seconds after 9:30:00.0000 UT

Fig. 37

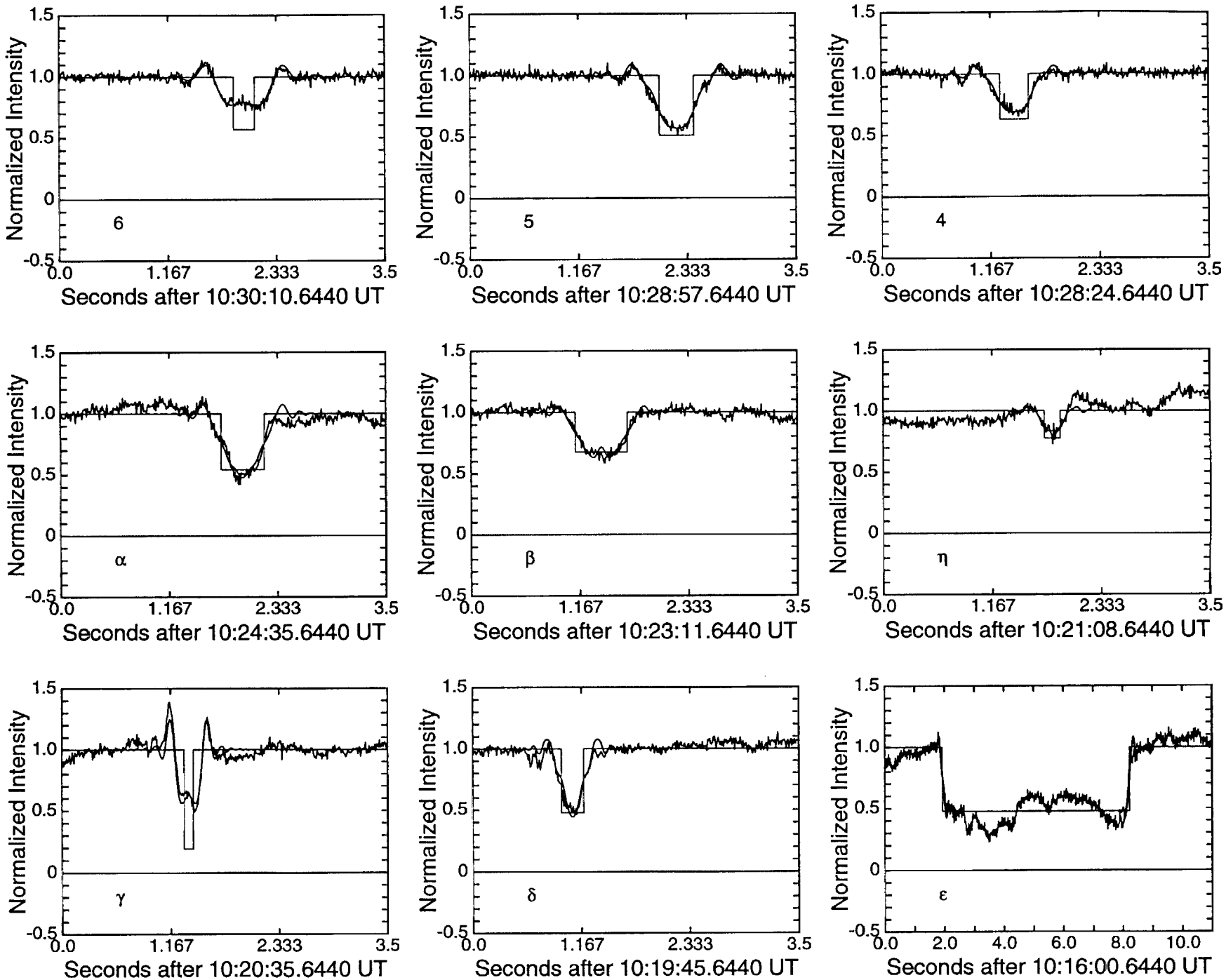
Normalized Intensity
1.5
1.0
0.5
0
-0.5
0.0
1.167
2.333
3.5
6
Seconds after 10:30:10.6440 UT
5
Seconds after 10:28:57.6440 UT
4
Seconds after 10:28:24.6440 UT
α
Seconds after 10:24:35.6440 UT
β
Seconds after 10:23:11.6440 UT
η
Seconds after 10:21:08.6440 UT
γ
Seconds after 10:20:35.6440 UT
δ
Seconds after 10:19:45.6440 UT
ε
2.0
4.0
6.0
8.0
10.0
Seconds after 10:16:00.6440 UT

Fig. 18

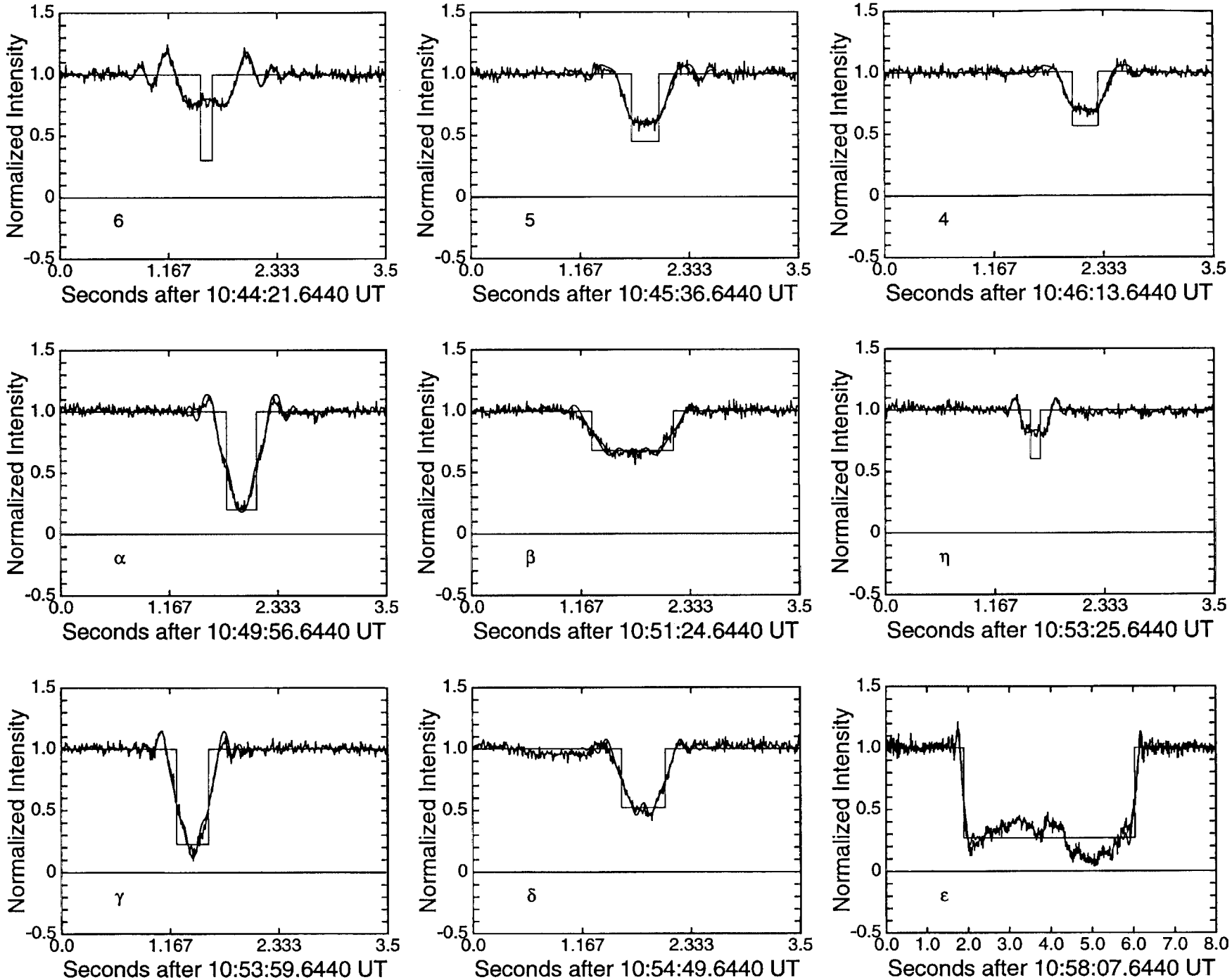
Normalized Intensity
1.5
1.0
0.5
0
-0.5
0.0
1.167
2.333
3.5
6
Seconds after 10:44:21.6440 UT
5
Seconds after 10:45:36.6440 UT
4
Seconds after 10:46:13.6440 UT
α
Seconds after 10:49:56.6440 UT
β
Seconds after 10:51:24.6440 UT
η
Seconds after 10:53:25.6440 UT
γ
Seconds after 10:53:59.6440 UT
δ
Seconds after 10:54:49.6440 UT
ε
0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0
Seconds after 10:58:07.6440 UT

Fig. 39