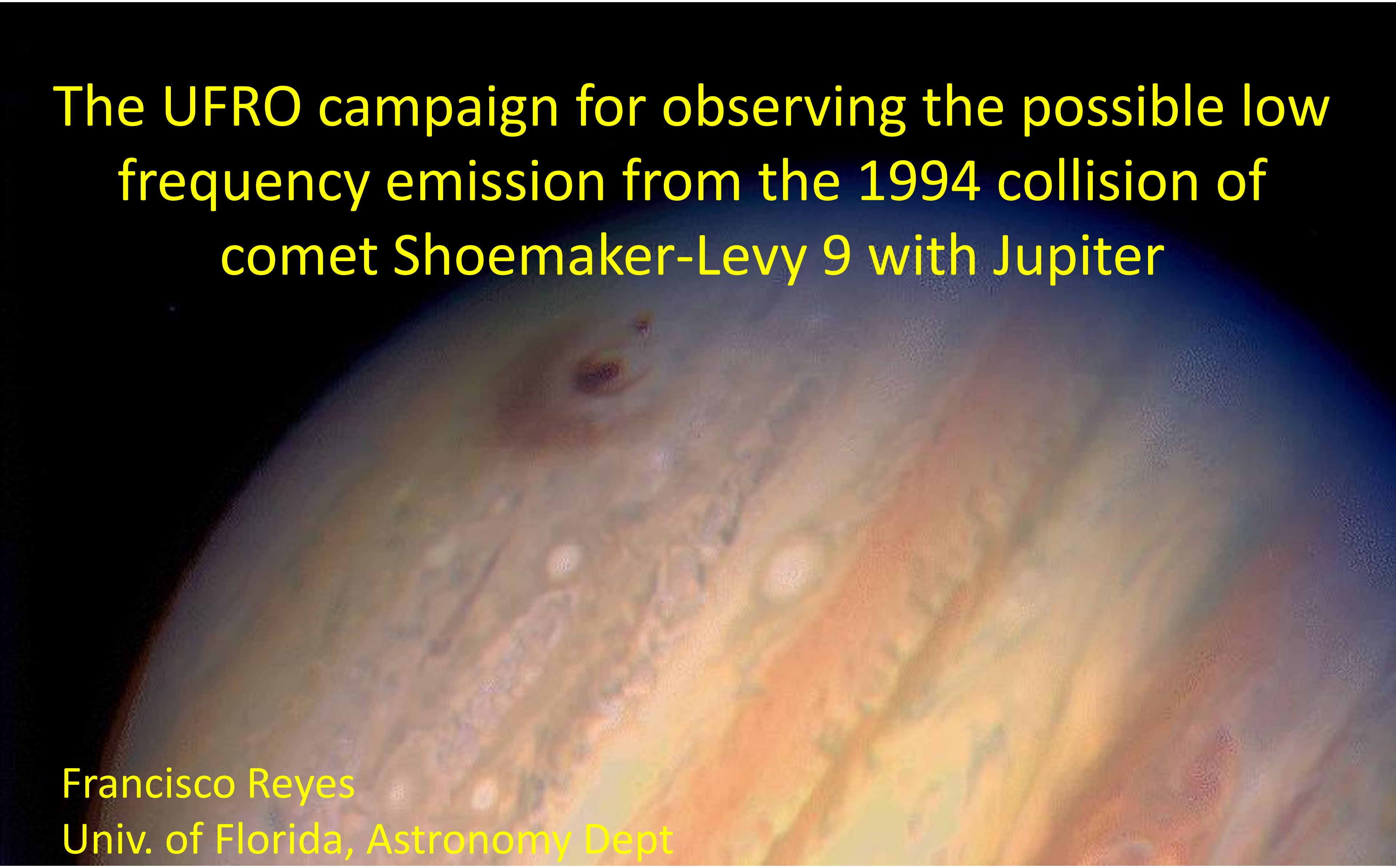


The UFRO campaign for observing the possible low frequency emission from the 1994 collision of comet Shoemaker-Levy 9 with Jupiter

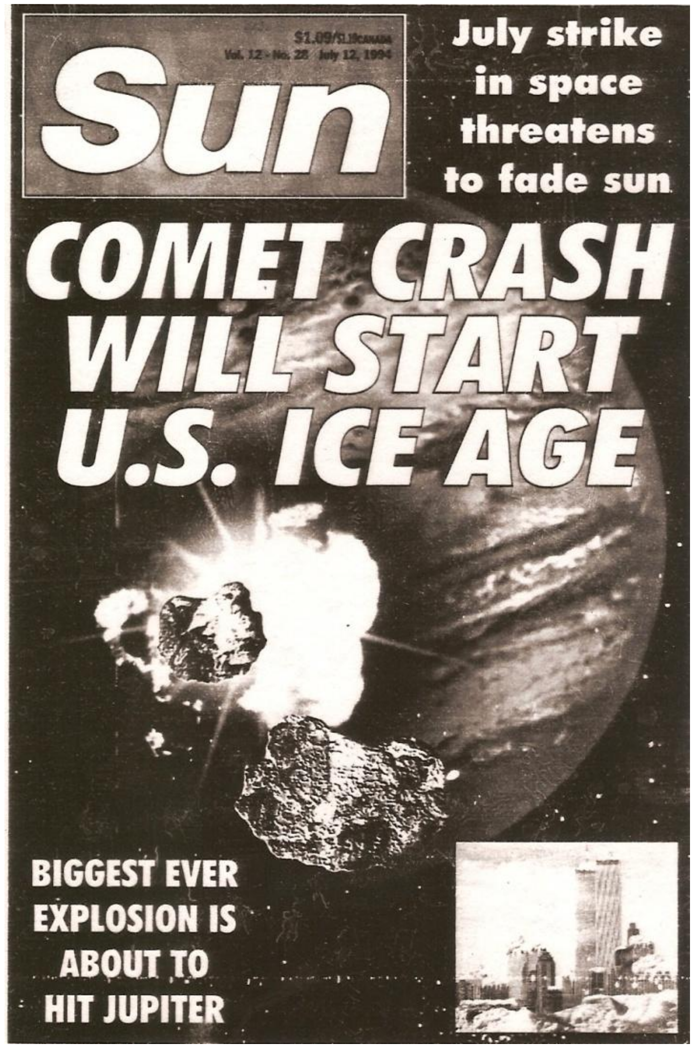
Francisco Reyes
Univ. of Florida, Astronomy Dept

Composite image of Jupiter and SL-9

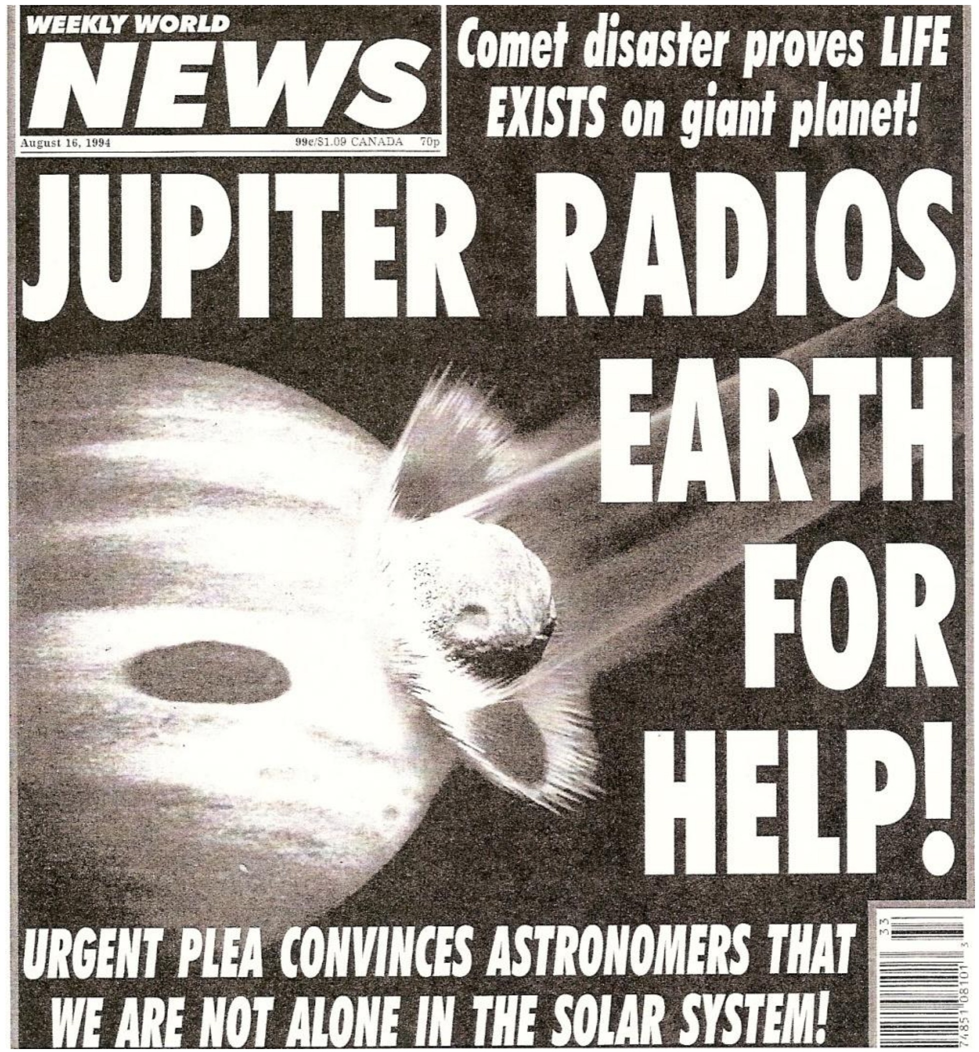
Before the collision of S-L 9 with Jupiter, there were several predictions regarding possible effects and emission from the collision…

- Some predictions dealt with the influence of the dust and its interaction with the energetic electrons and how that may influence the already known decametric and synchrotron radio emission
- Others addressed the topic of the electrodynamical effects of the passage of the fragments of the comet through the Jovian magnetosphere.
- But other predictions and results pointed to a completely different topic…

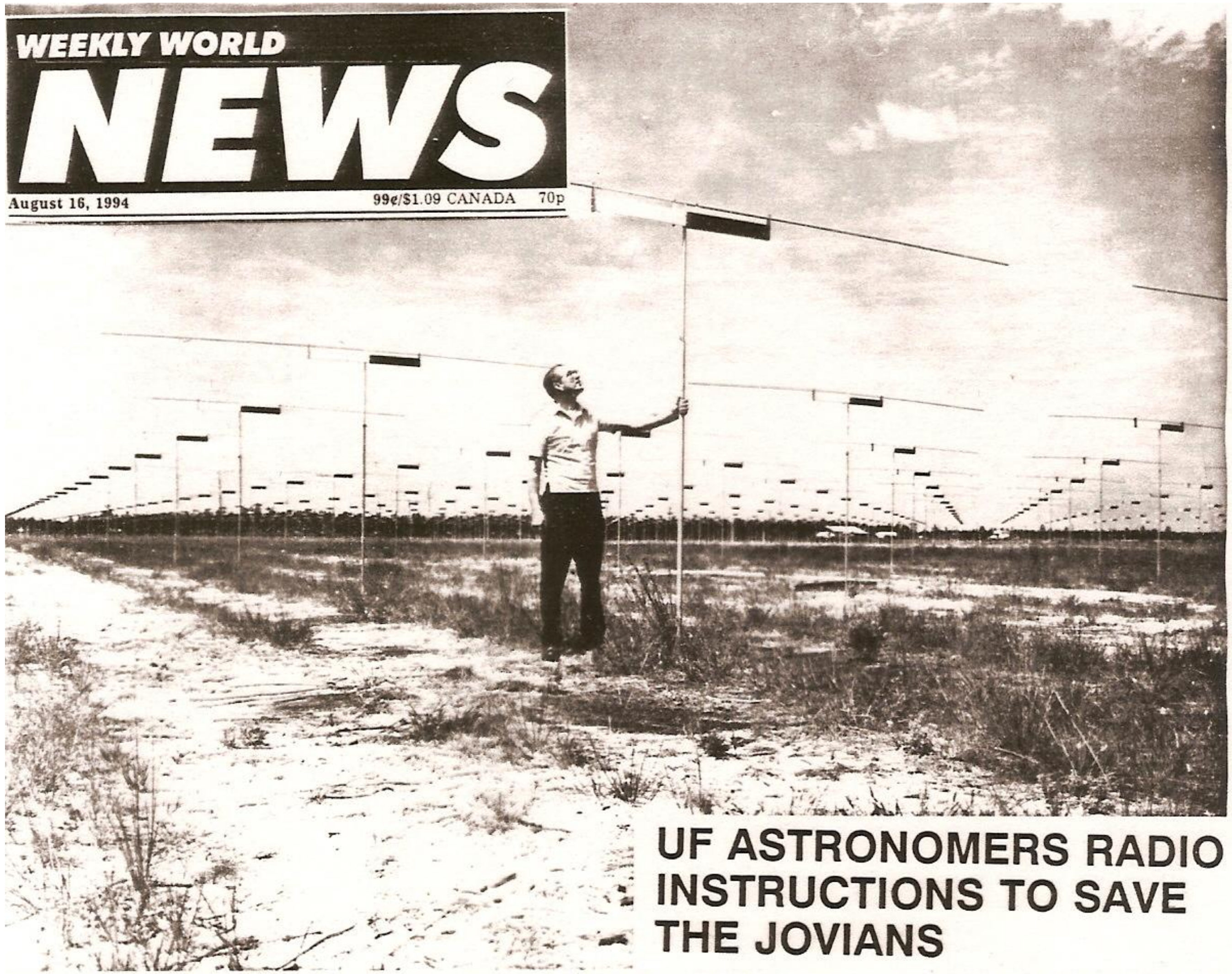
Here is one of these other predictions…



And some interesting results after the collision…



So Univ. of Florida radio astronomers using their large array of 640 dipoles at 26.3 MHz send instructions and offer to help…



Here are some papers published with predictions

- **Some interactions between dust from comet Shoemaker-Levy 9**
  A.J. Dessler and T. W. Hill
  Geophysical Research Letters Vol. 21, No. 11, pages 1043-1046, June 1, 1994
- **The Impact of comet Shoemaker-Levy 9 on the Jovian magnetosphere**
  Floyd Herbert
  GRL, Vol. 21, No. 11, pages 1047-1050, June 1, 1994
- **On possible magnetospheric dust interactions of comet Shoemaker-Levy 9 at Jupiter**
  W. –W. Ip and R. Prange
  GRL, Vol. 21, No. 11, pages 1051-1054, June 1, 1994
- **Plasma effects on the interaction of a comet with Jupiter**
  Paul. J. Kellogg
  GRL, Vol. 21, No. 11. pages 1055-1058, June 1, 1994
- **Hybrid simulation of comet Shoemaker-Levy 9 interaction with Jovian bow shock**
  A.S. Lipatov and A. S. Sharma
  GRL, Vol 21, No. 11, pages 1059-1062, June 1, 1994
- **Electrodynamical interaction between comet Shoemaker-Levy 9 and Jupiter**
  O. Bolin and N. Brenning
  GRL, Vol. 21, No. 11, Pages 1063-1066, June 1, 1994
- **Possible radio wave precursors associated with the comet Shoemaker-Levy 9/Jupiter impacts**
  W. M. Farrell, M. L. Kaiser, M. D. Desch and R. J. Mac Dowall
  GRL, Vol. 21, No. 11, pages 1067-1070, June 1 1994
- **The effect of comet Shoemaker-Levy 9 on Jupiter's synchrotron radiation**
  Imke de Pater
  GRL, Vol. 21, No. 11, pages 1071-1074, June 1, 1994

The Univ. of Florida group lead by Dr. Tom Carr (PI) submitted a proposal to NASA and was awarded a grant.
The funds were released just a few month before the collision.
It was necessary to buy more equipment, antennas, A/D converts and write software. And also to sent people and ship equipment and antennas to improve some stations and set up a new station (OVRO).

From where did the UF radio astronomers observed the effects of the collision?

- Univ. of Florida Radio Observatory (UFRO) in Dixie County (Old Town, Florida)
- Owens Valley Radio Observatory (OVRO, Caltech), Bishop, California
- Maipu Radio Observatory, Univ. of Chile (Near Santiago, Chile)

In addition,

- Three more radio astronomer contributed with data. From Tasmania (Dr. Bill Erickson), Japan (Dr. Koitiro Maeda) and Australia (Nigel Prestage)
- Dr. P. Kellog from Univ. of Minnesota set up a station, observed from South Africa and contributed with some data

These are the people and the institutions involved with the UF network
The PI for the project was Dr. Tom Carr
F. Reyes was the coordinator for the International Jupiter Watch (IJW) Decametric Wavelength Network

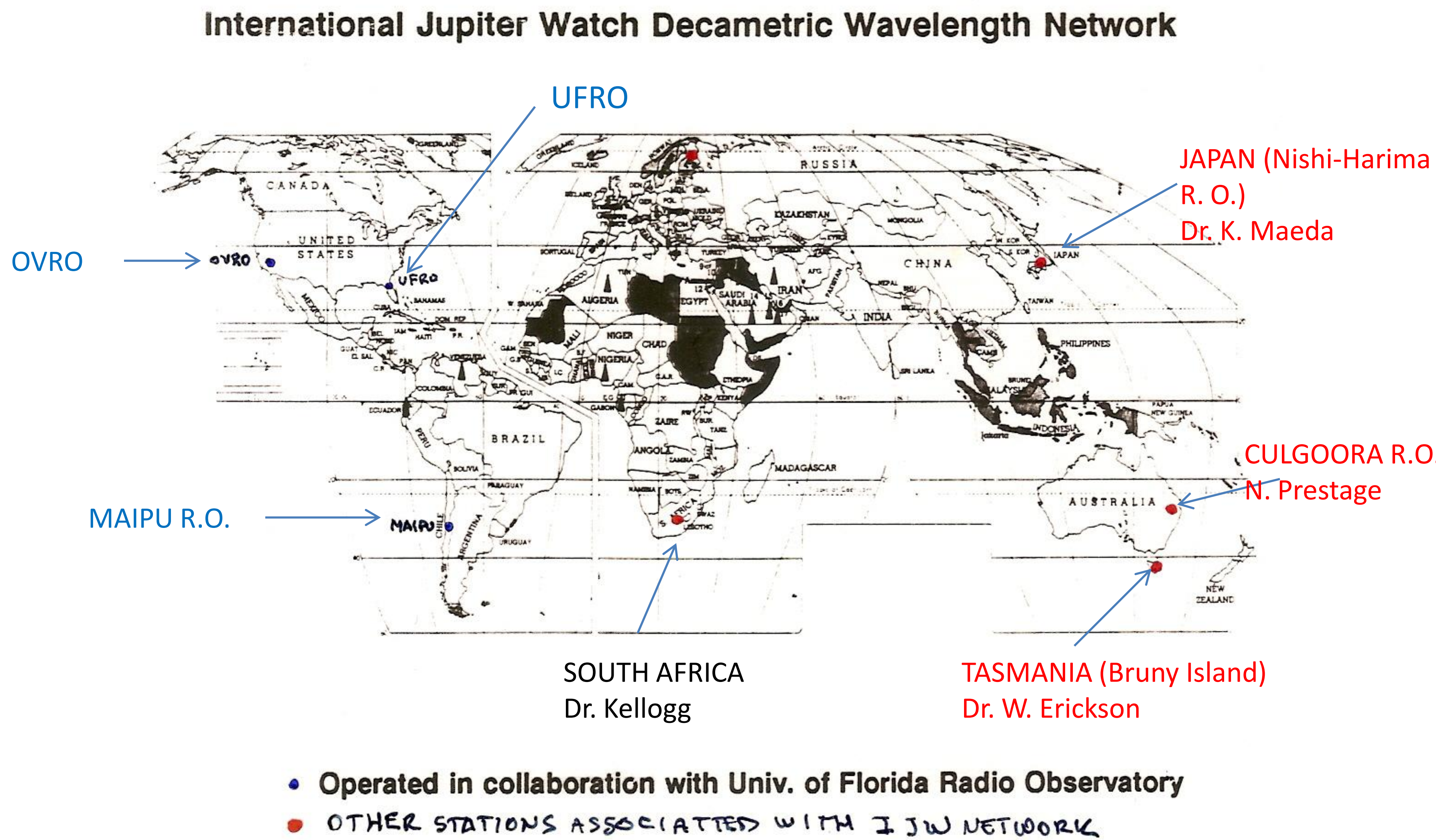
A Search for Decametric Wavelength Radio Emission from the Collision of Comet S-L 9 with Jupiter

F. Reyes[1], T.D. Carr[1], C. Higgins[1], L. Garcia[1], W.B. Greenman[1], J.A. Phillips[2], L. Wang[6], J. May[3], W.C. Erickson[4], K. Maeda[5], N. Prestage[7], J. Aparici[3], H. Alvarez[3], F. Olmos[3], C. Phillips[4], A. Vrana[4], N. Tokimasa[8], and T. Kuroda[8].

[1] Dept. of Astronomy, University of Florida
[2] Antares Virtual Reality Systems
[3] Dept. of Astronomy, University of Chile
[4] Dept. of Physics, University of Tasmania
[5] Dept. of Physics, Hyogo College of Medicine
[6] Applied Research Corporation
[7] IPS Radio and Space Services, Culgoora Solar Observatory
[8] Nishi-Harima Astronomical Observatory

Tony Phillips and Wes Greenman were in charge of building and the set up of the OVRO station
F. Reyes was in charge of writing the software for the A/D converter and the interfaces at Maipu R.O.
J. Levy contributed to the equipment. James De Buizer to the observations at UFRO

Location of the observing sites that contributed to data to the UFRO group



These are the frequencies used by the stations for observing during the period of the collision

Radio observatory	Frequencies (MHz)
UFRO-Maipu-OVRO	16, 18, 20, 22.2, 24, 26.3, 27, 28.4, 32 26.3 MHz large array 18-36 MHz spectrograph
Bruny Island	5-36 MHz spectrograph
Nishi-Harima	18-36 MHz spectrograph 22 MHz interferometer 23.3, 24.4, 25.0, 25.3, 25.5 MHz Radiometers
Culgoora	18-57 MHz spectrograph

List of fragments observed by UFRO group and the contributed stations from different sites

Impact of fragments of SL-9 observed by different groups

Group	Fragment	No. Fragm.
UFRO-MAIPU-OVRO	A B C F H J L Q2 Q1 R T U	12
Maeda (Japan)	C D G K N W	6
Erickson (Tasmania)	D E G K N R S	7

Combined No. of observed fragments= 19

Jovian activity and hours of observations by the UFRO groups during 1994

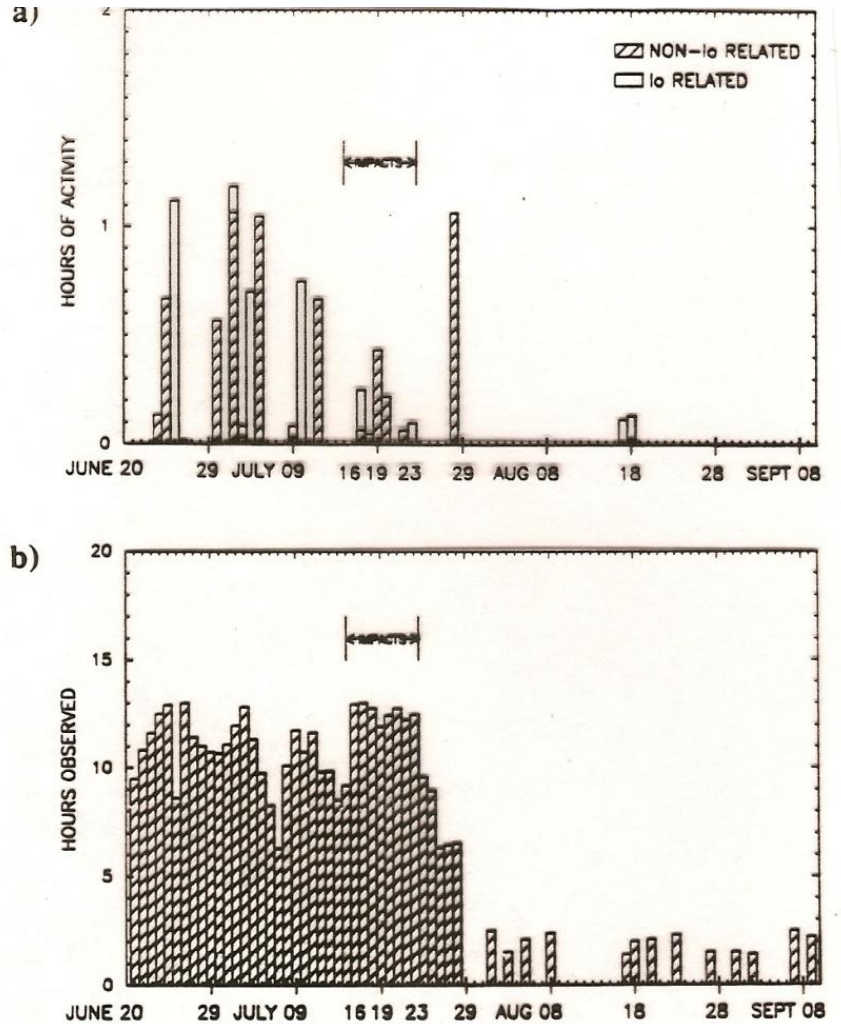
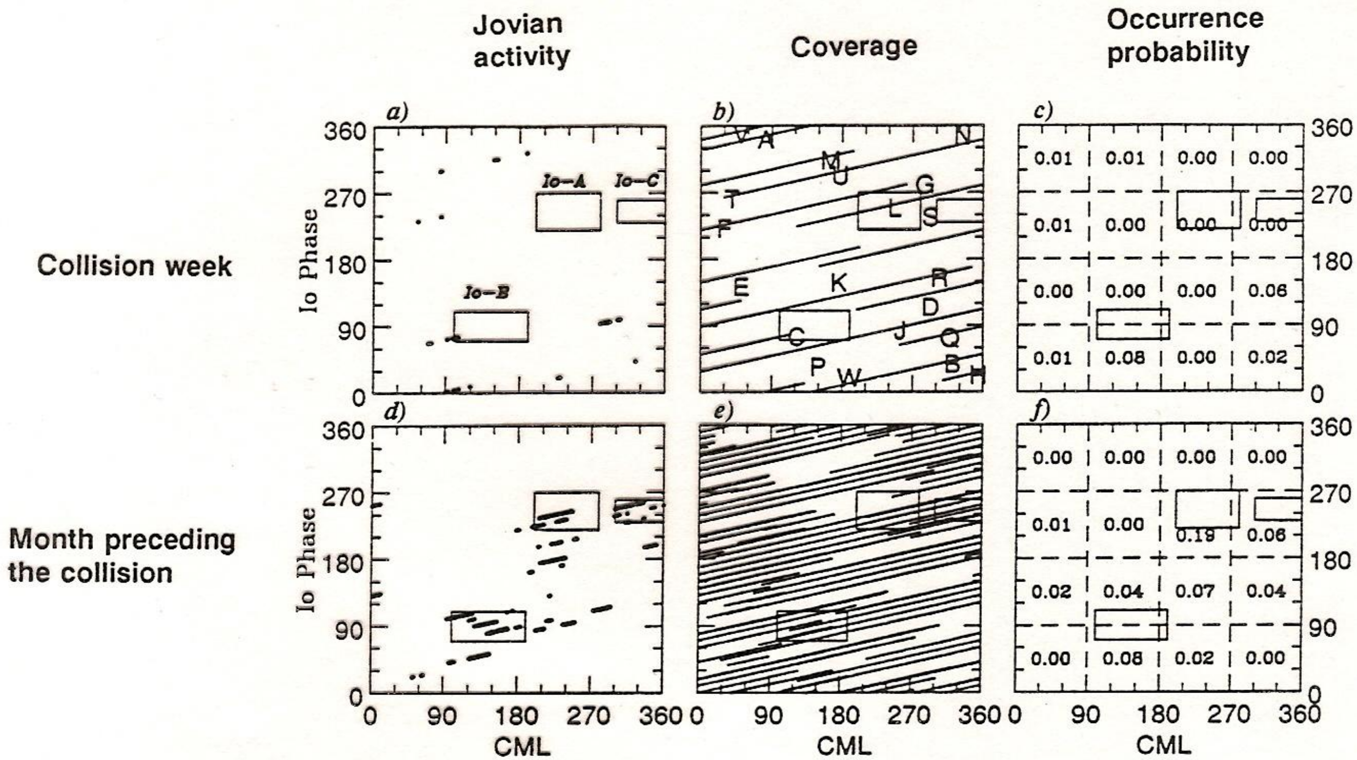


Figure 1. **a) Histogram showing duration of Jovian decametric burst activity observed on each day of an 80-day period including the week of impacts. b) Coverage histogram for above, giving the observing time each day.**

CML-Io Phase covered by UFRO group



Jovian decametric activity, coverage, and occurrence probabilities from UFRO, Maipu, and OVRO displayed on the CML vs Io phase plane. Values of CML and Io phase at fragments impact times are indicated approximately by the positions of the letters (Ref.: Carr et al., GRL, Vol 22, 1785, 1995).

CML= Central Meridian Longitude of System III

Io Phase = Angle of Io from location opposite to Earth (Superior geocentric conjunction)

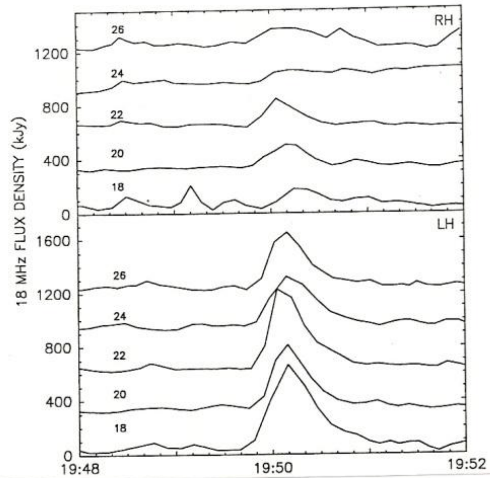
Strategy in the search for low frequency emission triggered or enhanced by the S-L 9 comet

- Search for pulses of emission close to the collision time of the fragments
- Search for continuous emission from Jupiter using the 26.3 MHz large array
- Search for an increase of the occurrence probability of the normal decametric emission during the week of the collision.

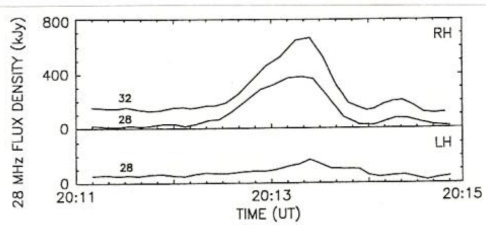
Search for bursts near the collision of the fragments

Plot of two short polarized pulses received close to the collision of fragments Q1 and Q2

UFRO July 20, 1994



Burst A received at 19:50:10 UT, 1.5 standard deviations after the accepted impact time of fragment Q2. Impact time of Q2 was 19:44 UT, with a standard deviation of 4 minutes



Burst B received at 20:13:20 UT, about 1 standard deviation before the accepted impact time of Q1. The impact time of Q1 was at 20:13:52 UT with a standard deviation of 30 seconds.

Characteristics of bursts A and B received near the collision of fragments Q1 and Q2

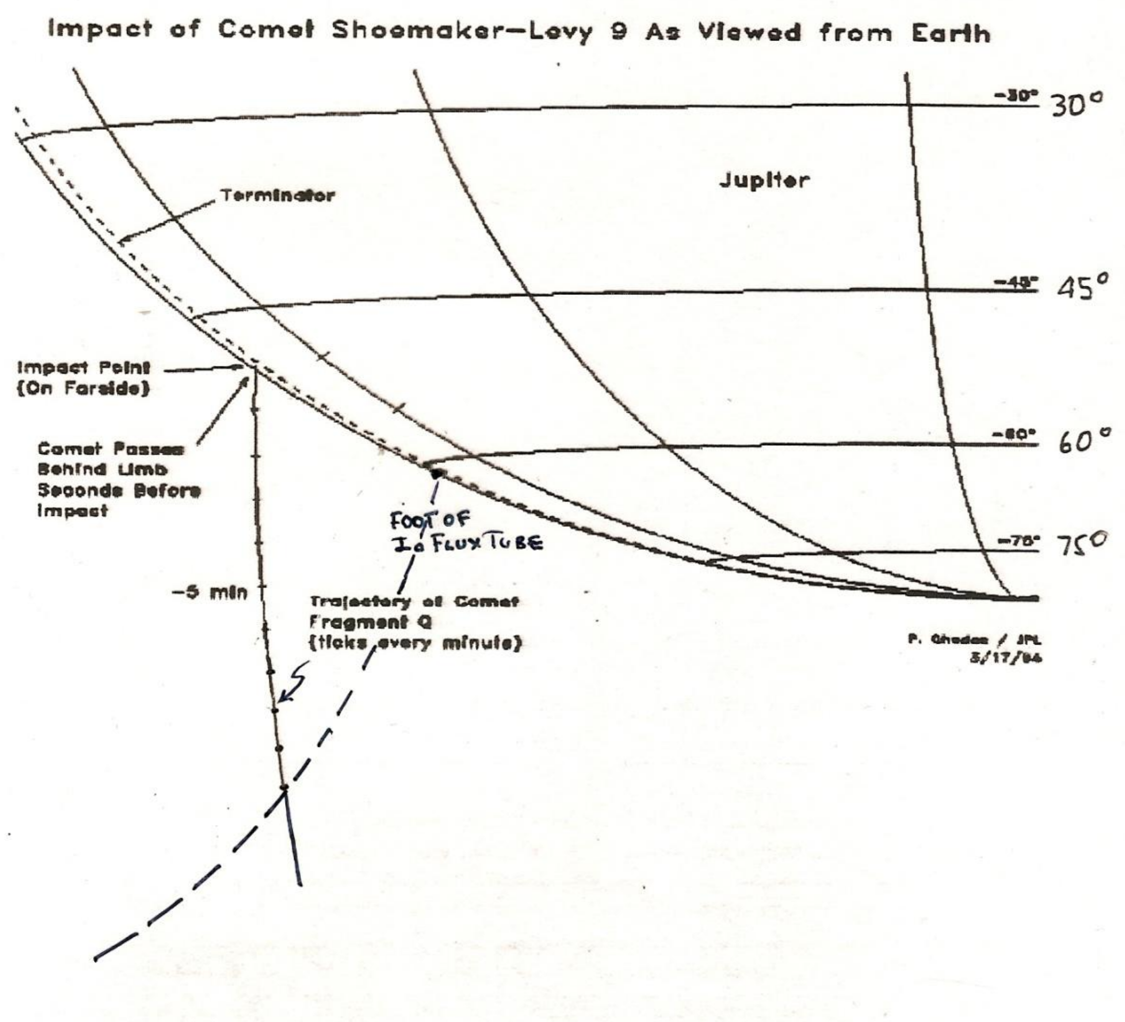
Table 3. Characteristics of bursts A and B. The peak flux density is S. AR is the polarization axial ratio, *(mincr axis length)/(major axis length)*. (It is assumed that there is no unpolarized component.)

Burst	Freq. (MHz)	S (kJy)	Duration	Polarization Sense	Polarization AR
A	18	850		LH	+0.23
	20	620		LH	+0.21
	22	920	54^s	LH	+0.22
	24	840		LH	+0.26
	26	480		LH	+0.22
B	28	480	$1^s\ 15^s$	RH	-0.24
	32	700		(RH)	*

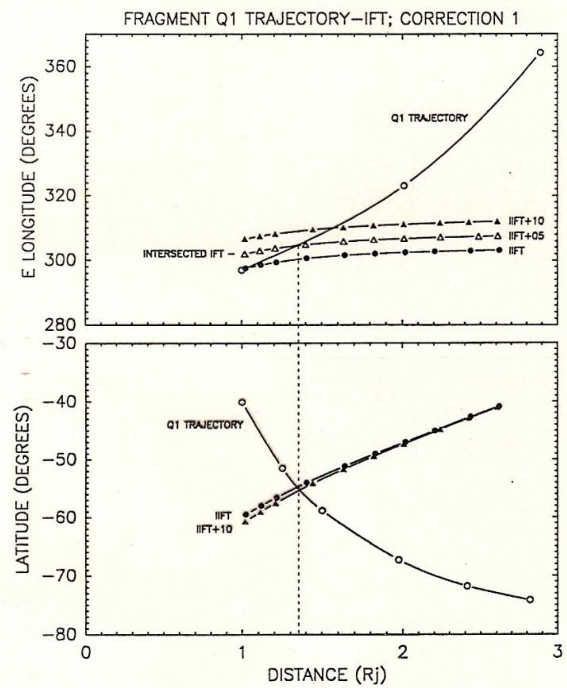
AR: Axial Ratio of polarization
LH: Circular left hand polarization
RH: Circular right hand polarization

* No LH polarization information at 32 MHz

Projected image of the trajectory of fragment Q and the location of the Io flux tube



Longitude, latitude and distance of the trajectory of fragment Q1 and the location of Io flux tubes (IFT), IFT+5 degrees and IFT+10 degrees



Fragment Q1 trajectory-IFT. An IFT located 5 degrees downstream from Io may have been intersected by the fragment. Approximate coordinates of intersection point are $R=1.35\ R_J$, E longitude=304 degrees, latitude=-55.5 degrees.

These two bursts were observed at UFRO before sunset. They were not observed by any other station, including the South Africa station run by Dr. P. Kellogg (University of Minnesota).

Plots of data obtained by Dr. Kellogg from South Africa around the collision of the Q1 and Q2 fragments

Q1

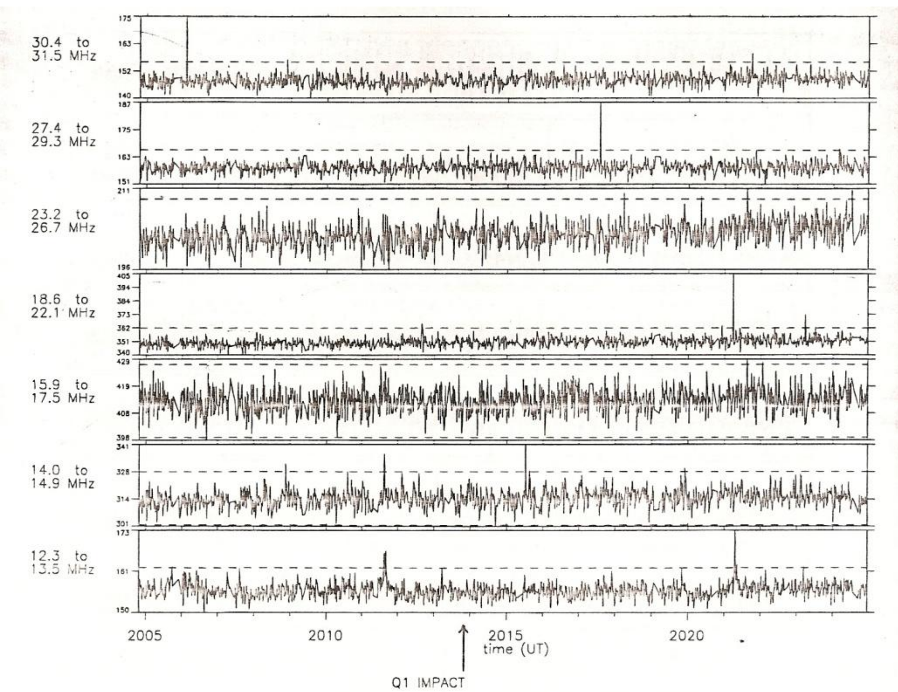


FIG. 5.—Signal in the quiet bands of Fig. 4, for the Q1 impact

Q2

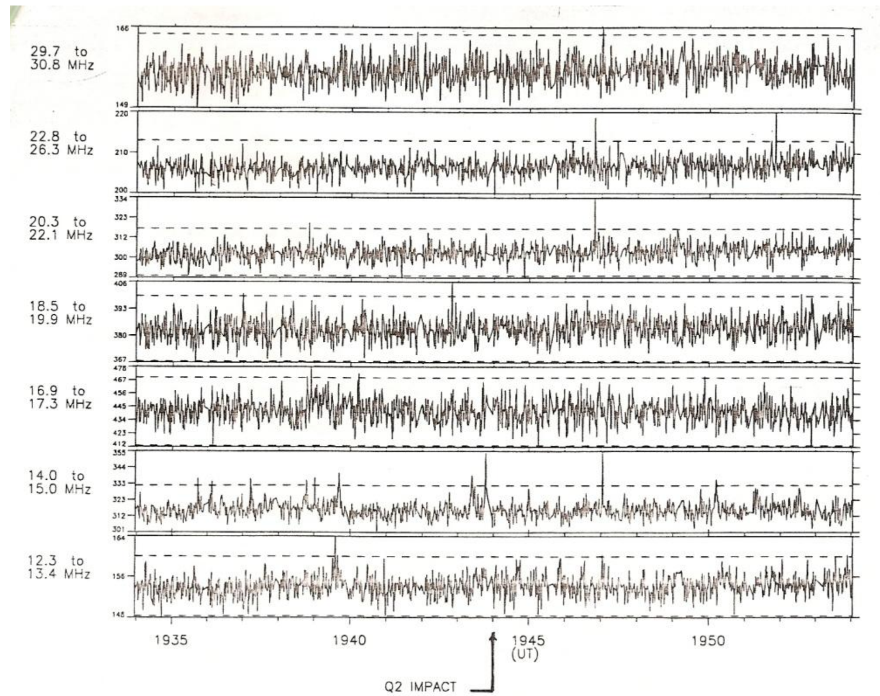
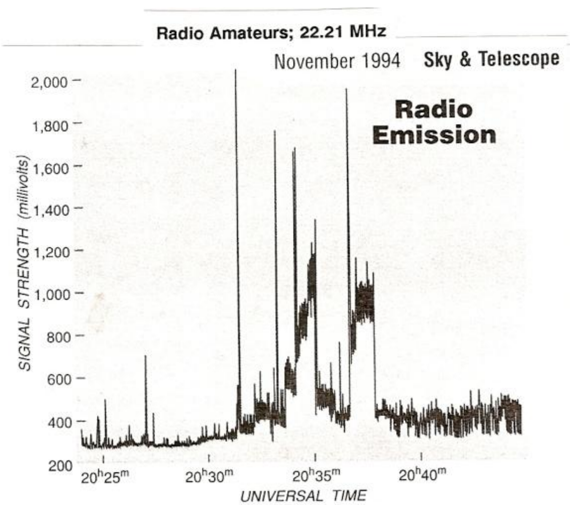


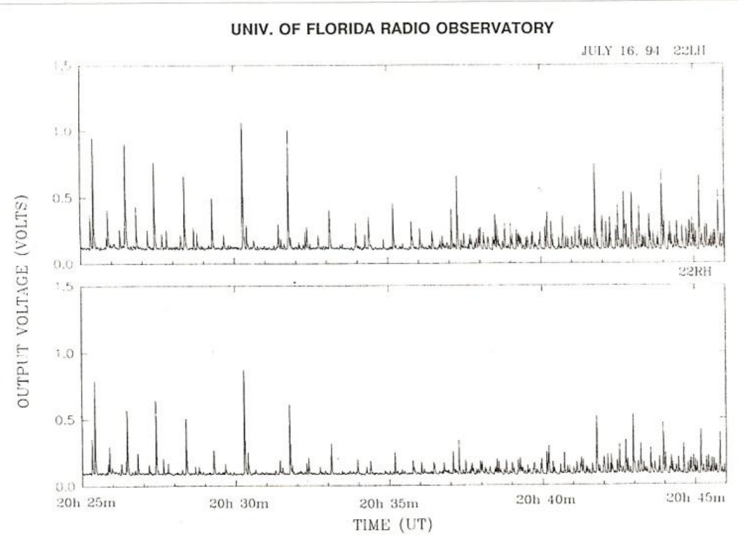
FIG. 6.—Signal in the quiet bands for about 20 minutes centered on the Q2 impact

No deflections were observed in South Africa during or near the collision of Q1 and Q2. The Sun had set in South Africa at the time of the collision. Dr. Kellogg suggestion was that the two bursts received at UFRO could be solar bursts .

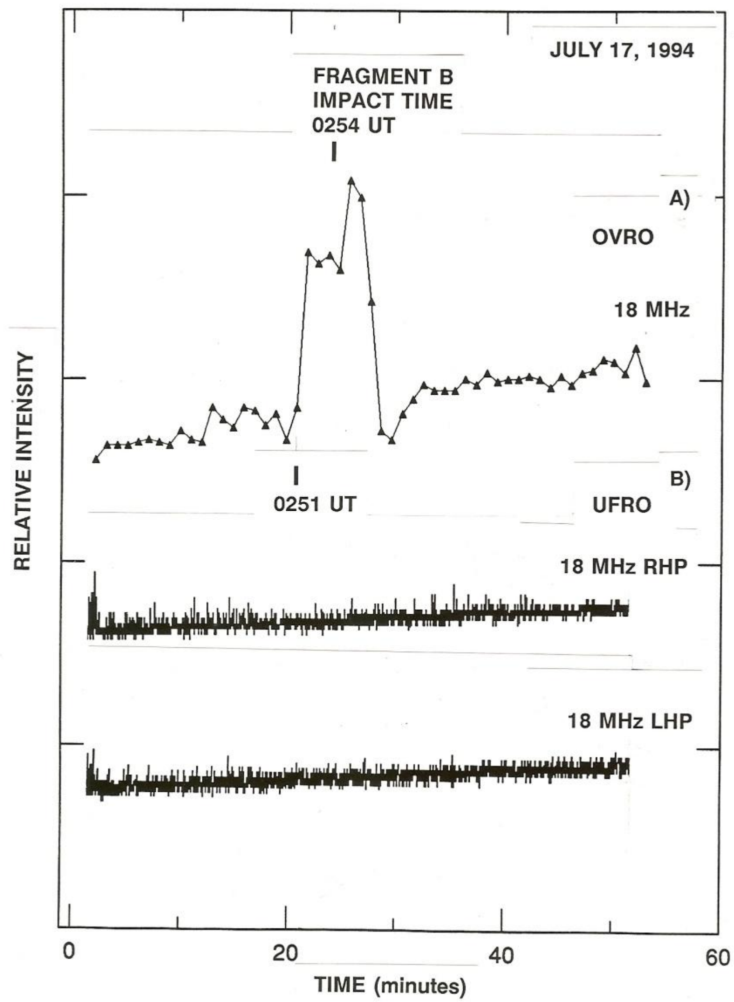
Emission claimed to have been detected at 22.21 MHz on July 16 from a group of radio amateurs (Article appeared in Sky and Telescope, November 1994 issue)

Comparison with a plot from the observations at 22.2 MHz from UFRO from approximately the same period of time.

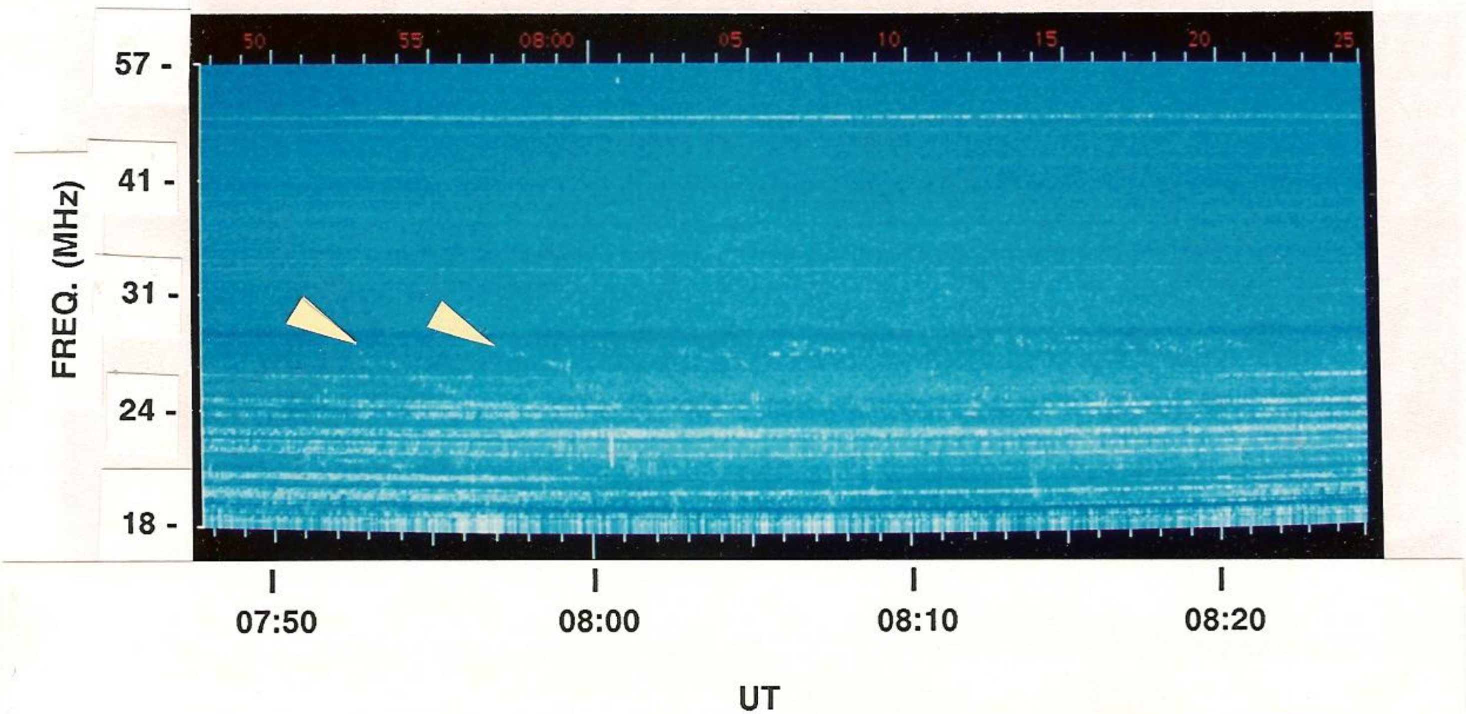




Emission detected at OVRO on July 17 during the collision of fragment B at 18 MHz. Comparison with a plot of the observation at UFRO at the same frequency



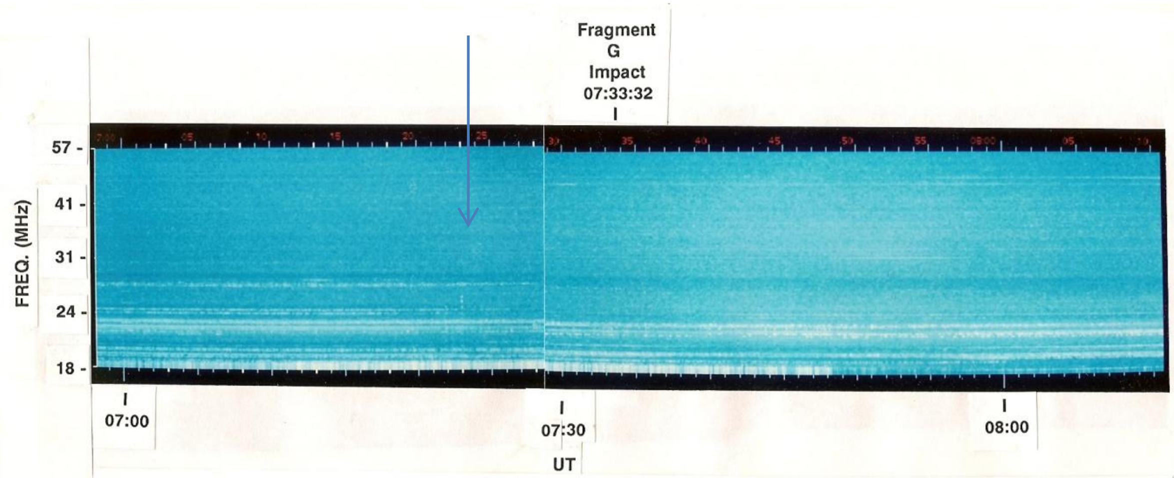
An example of emission detected from a predicted Io-B storm at Culgoora R. O. on July 17, 1994



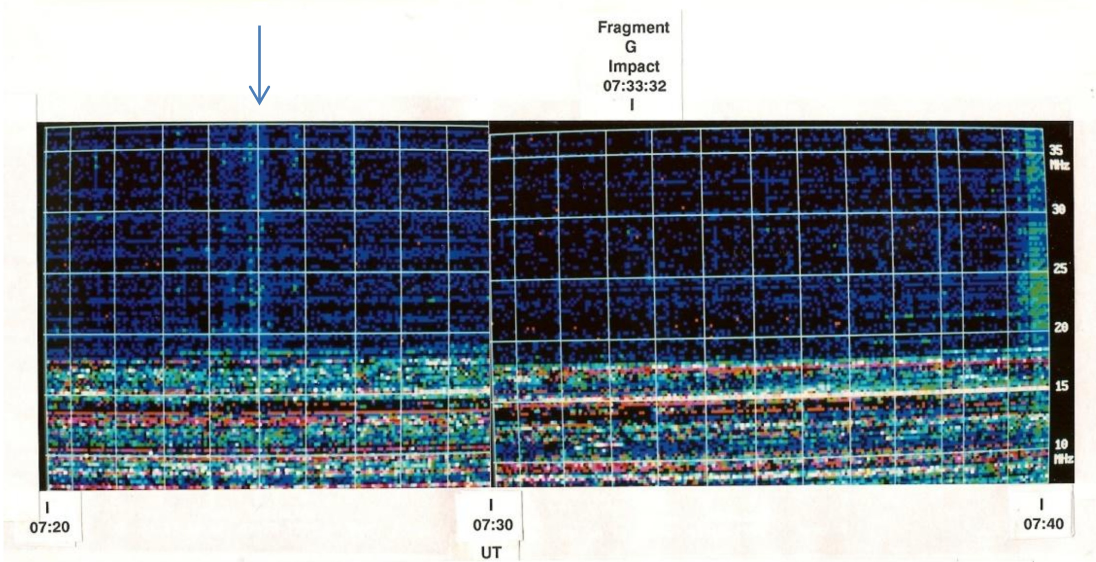
Dynamic spectrum obtained at Culgoora Solar Radio Observatory on July 17, 94.
Arrows show Jovian decametric arcs from a predicted Io-B storm.
Impact of fragment C occurred at 07:12 UT; no emission associated with this fragment was detected.

Short, weak burst detected at Culgoora and Tasmania.

Note that there is about 2 minutes difference between the bursts



Dynamic spectrum obtained at Culgoora Solar Radio Observatory on July 18, 94 near the collision time of fragment G. No emission associated with the collision of the fragment was originally reported. The short bursts around 07:22-07:23 UT are being investigated.



Dynamic spectrum obtained at Bruny Island Radio Observatory (Tasmania) on July 18, 94 near the collision time of fragment G. No emission associated with the collision of the fragment was originally reported. The short bursts around 07:24-07:25 UT are being investigated.

Search for continuous emission from Jupiter

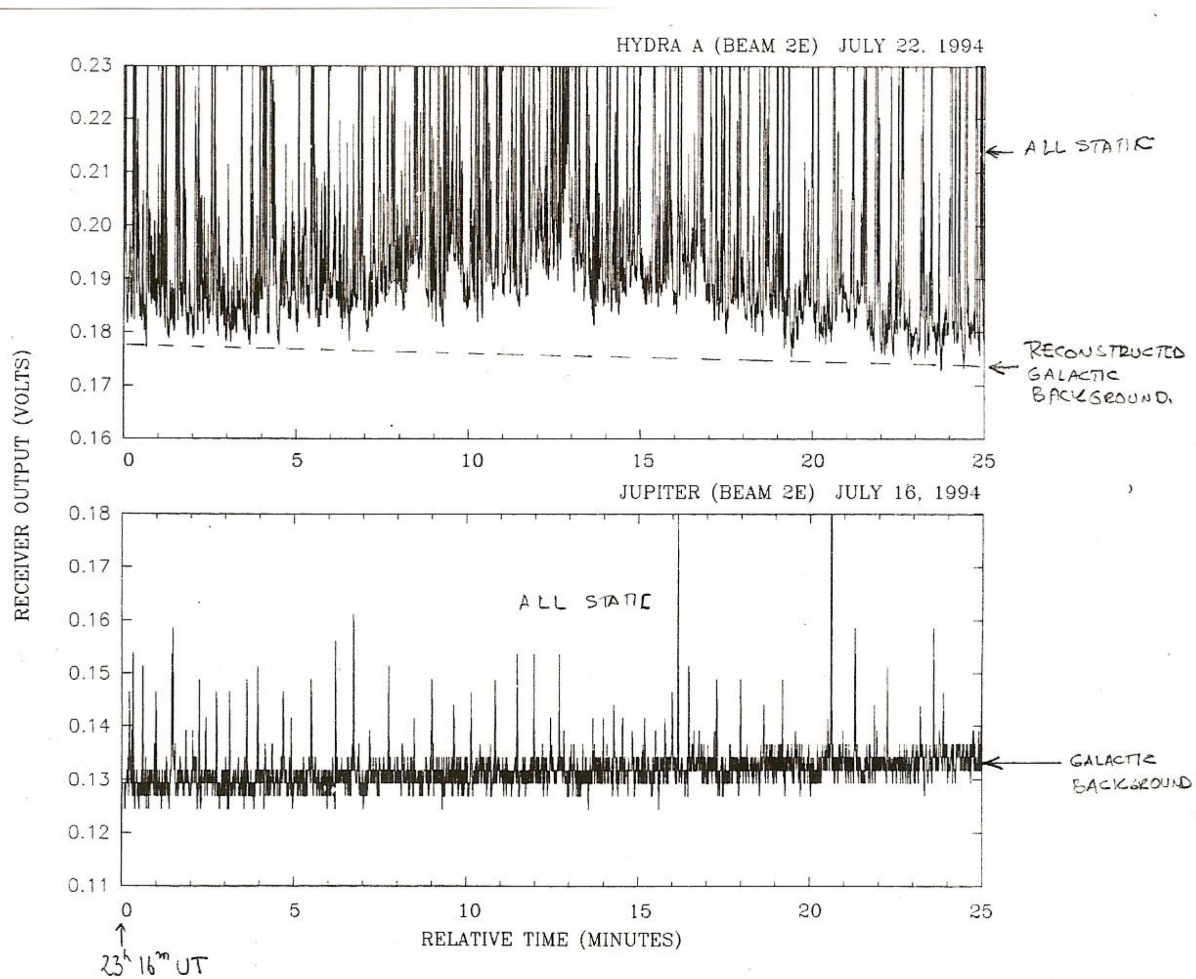
Observations with the 26.3 MHz large array (640 dipoles) at UFRO

TABLE 3. Observing periods with the large UFRO 26.3 MHz radio telescope on comet impact days. Asterisks indicate the impacts which occurred while the observations were in progress. The minimum detectable flux density for very long Jovian bursts (> 4 s duration), or for continuum emission, was about 1 kJy. No such activity was observed in any of the periods listed. Small amounts of ordinary L burst activity were observed as indicated.

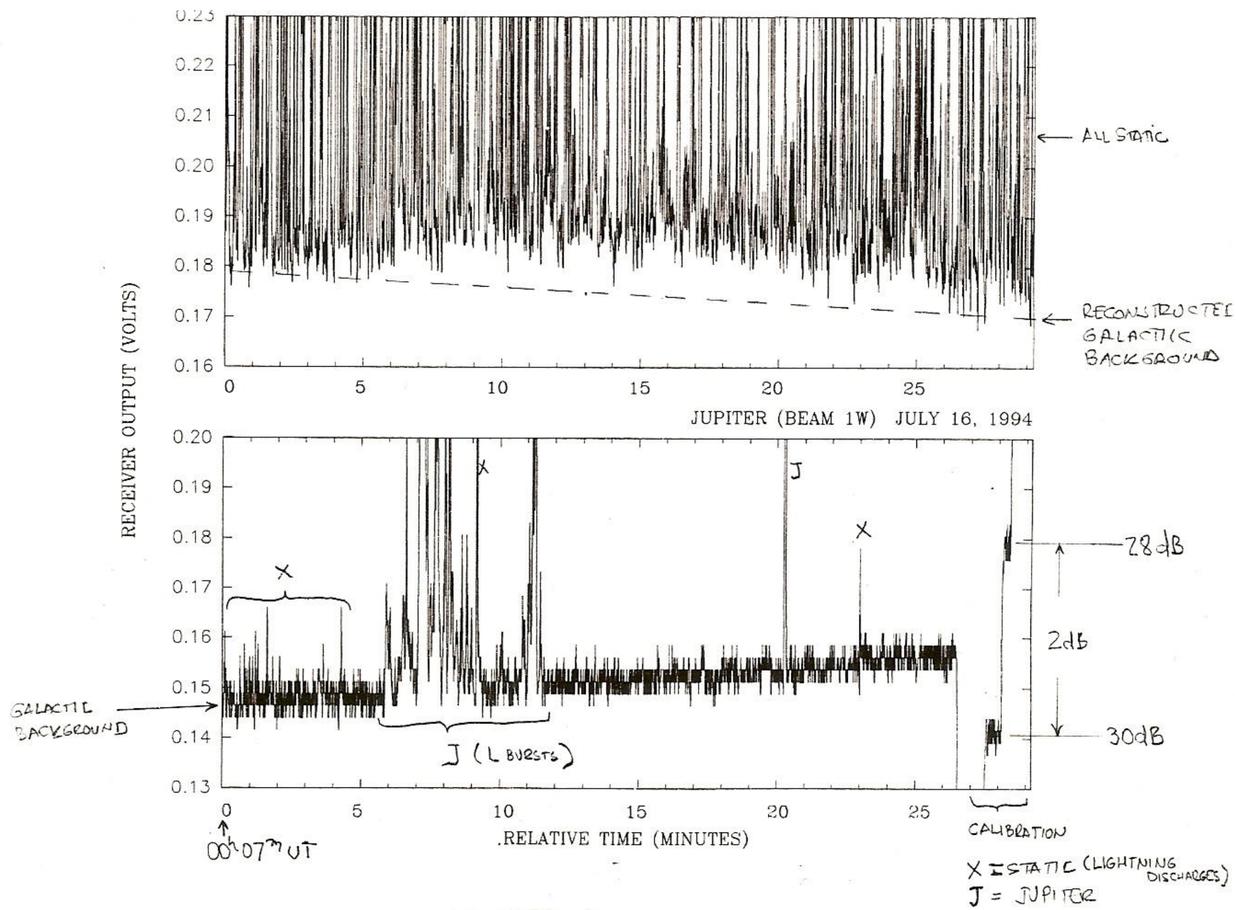
Frag-ment	Impact Date UT	Observing Period UT	Observing Period Relative to Impact	L-Burst Activity Rel. to Impact
A	7/16 20 : 11	22 : 25 to 01 : 49	$+2^h15^m$ to $+5^h38^m$	none
B	7/17 02 : 50	22 : 25 to 01 : 49	-4^h25^m to -1^h01^m	-2^h35^m to -2^h30^m
F*	7/18 00 : 33	22 : 31 to 01 : 45	-2^h02^m to $+1^h12^m$	-0^h50^m to -0^h10^m
H	7/18 19 : 32	22 : 18 to 01 : 42	$+2^h26^m$ to $+6^h10^m$	$+4^h14^m$ to $+4^h25^m$
L*	7/19 22 : 17	22 : 14 to 01 : 38	-0^h03^m to $+3^h21^m$	none
Q2	7/20 19 : 44	22 : 10 to 01 : 34	$+2^h26^m$ to $+5^h50^m$	none
Q1	7/20 20 : 12	22 : 10 to 01 : 34	$+1^h58^m$ to $+5^h22^m$	none
R	7/21 05 : 33	22 : 10 to 01 : 34	-7^h21^m to -3^h59^m	none
T	7/21 18 : 10	23 : 45 to 01 : 31	$+5^h35^m$ to $+7^h21^m$	none
U	7/21 21 : 55	23 : 45 to 01 : 31	$+1^h50^m$ to $+3^h36^m$	none
V	7/22 04 : 22	23 : 45 to 01 : 31	-4^h37^m to -2^h51^m	none

A comparison plot of emission from radio source Hydra A on July 22 and the galactic background emission on July 16 made with the 26.3 MHz large array, beam 2E

Jupiter was in the beam of the large array on July 16. A continuous emission from Jupiter should show up as an increase of the level centered in the beam



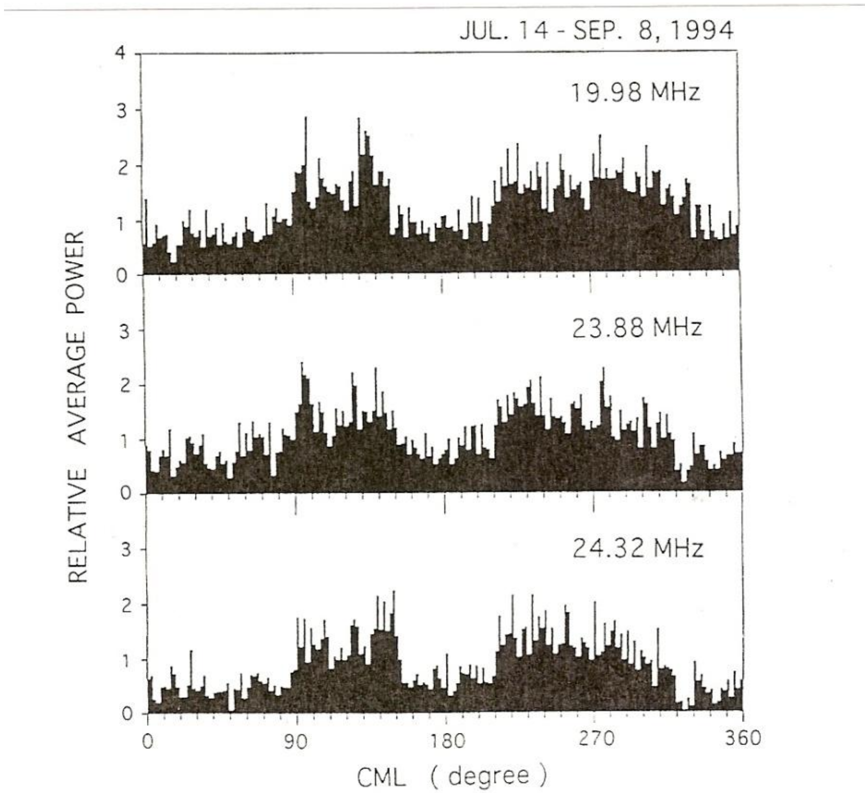
Upper panel: Emission from Hydra A radio source (26.3 MHz array)
Lower panel: Jupiter emission received by the 26.3 MHz large array, beam 1W



Report of integrated emission observed and reported by the group lead by Dr. H. Oya from Tohoku University, Japan (Reported in Step GBRSC News)

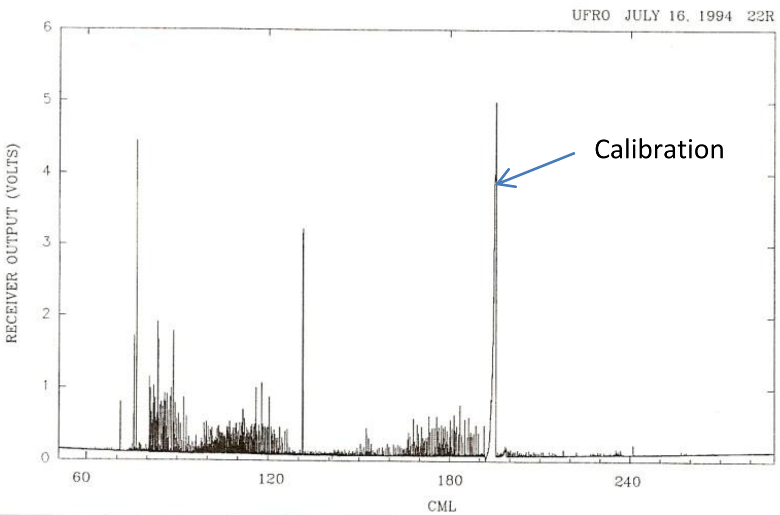
Jupiter emission are integrated over the period July 14 to September 8, 1994

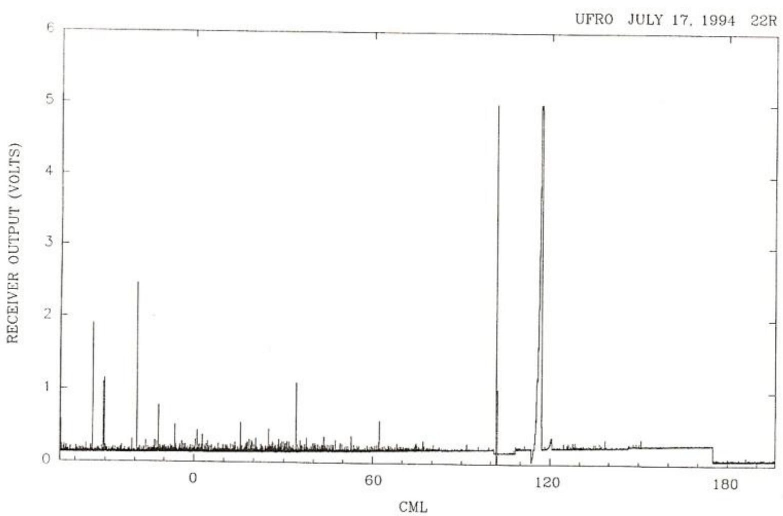
Plot of intensity of emission as function of CML

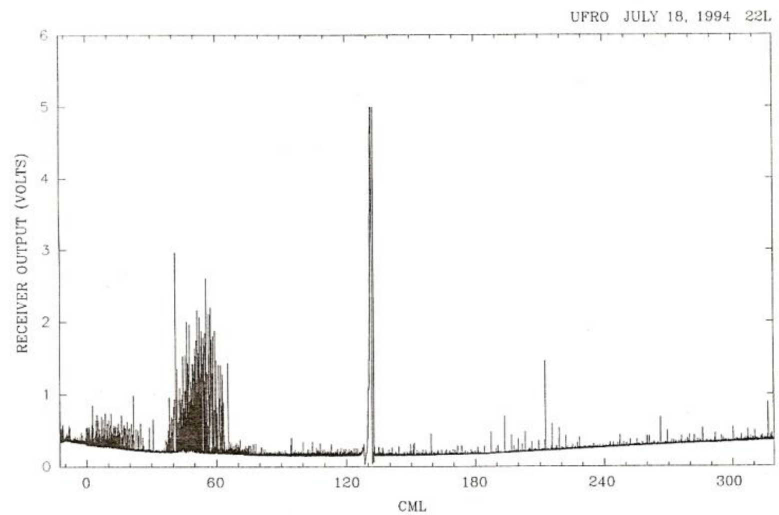


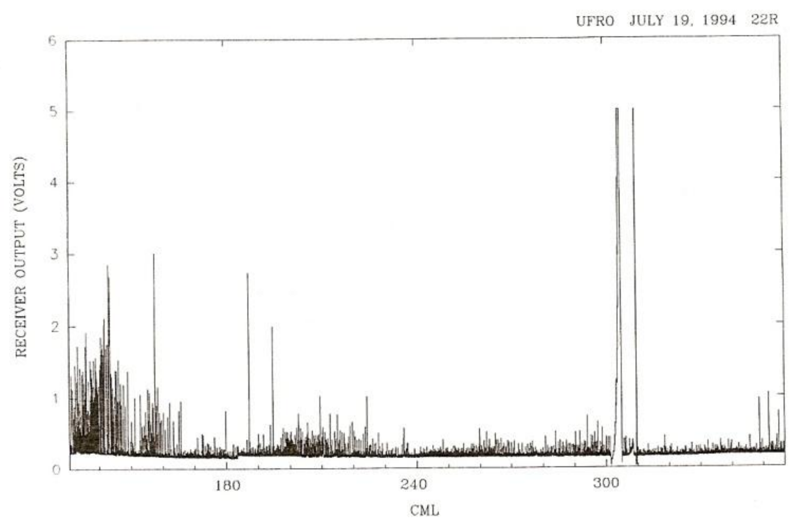
Integration of records of the decameter wave radiation observed from July 14 to September 8, 1994 plotted on the coordinate of the Jovian system III central meridian longitude (CML) for radiometer observations at 19.98 MHz, 23.38 MHz and 24.32 MHz observed at Zao station. There are two remarkable major sources at Jupiter which are distributed from 90° to 150° and from 210° to 320°. The emission feature after the passage of the shoemaker-Levy 9 comet has then been completely changed to the feature of a pulsar compared with the previous cases (in the bottom panel); that is , the decameter wave are emitted being switched from the north to south polar region sources, and vice versa, synchronizing with the half of Jovian rotation period.

Comparison of **interference** (lightning discharges) received on July 16, 17, 18 and 19 at UFRO

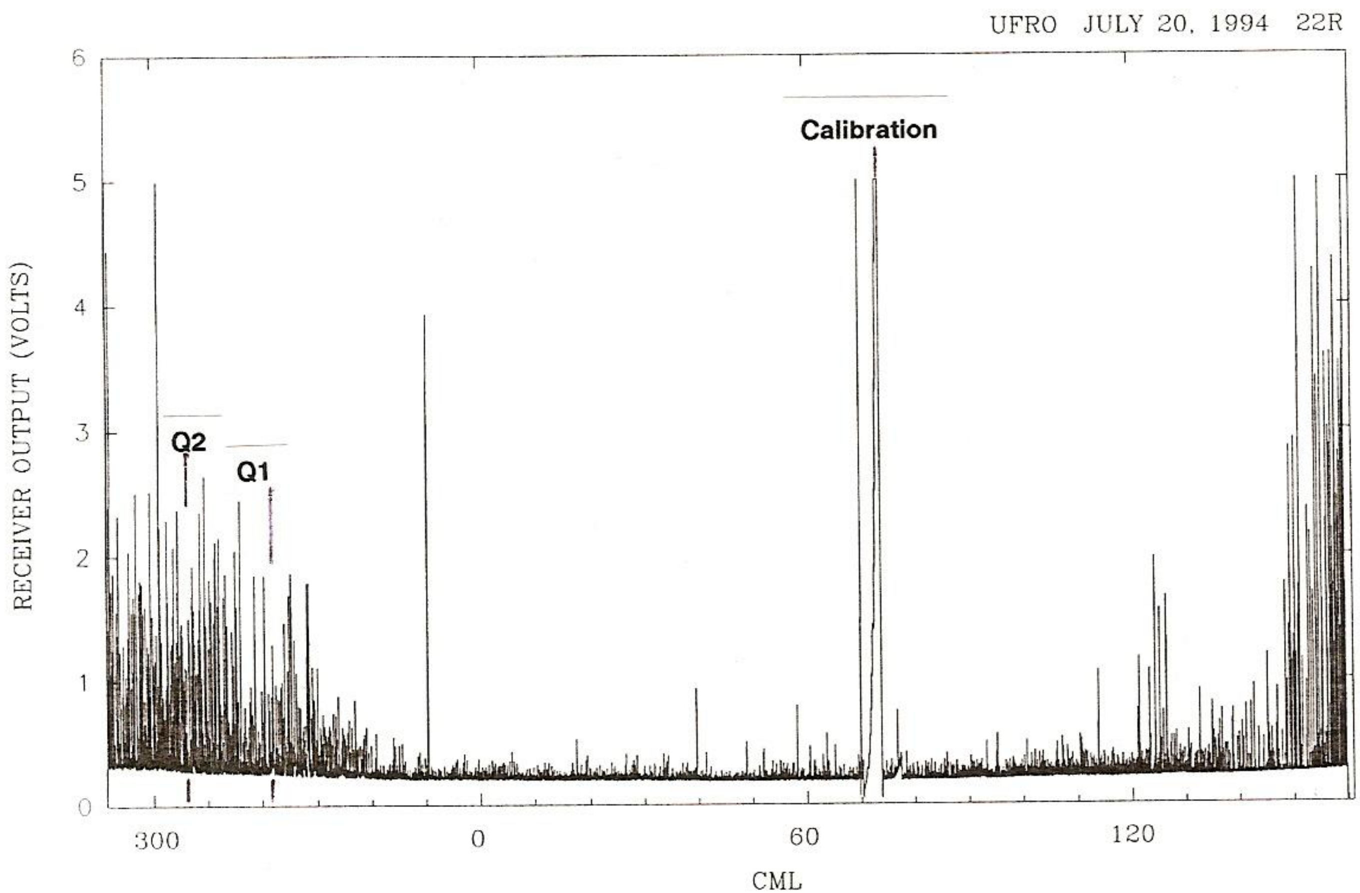








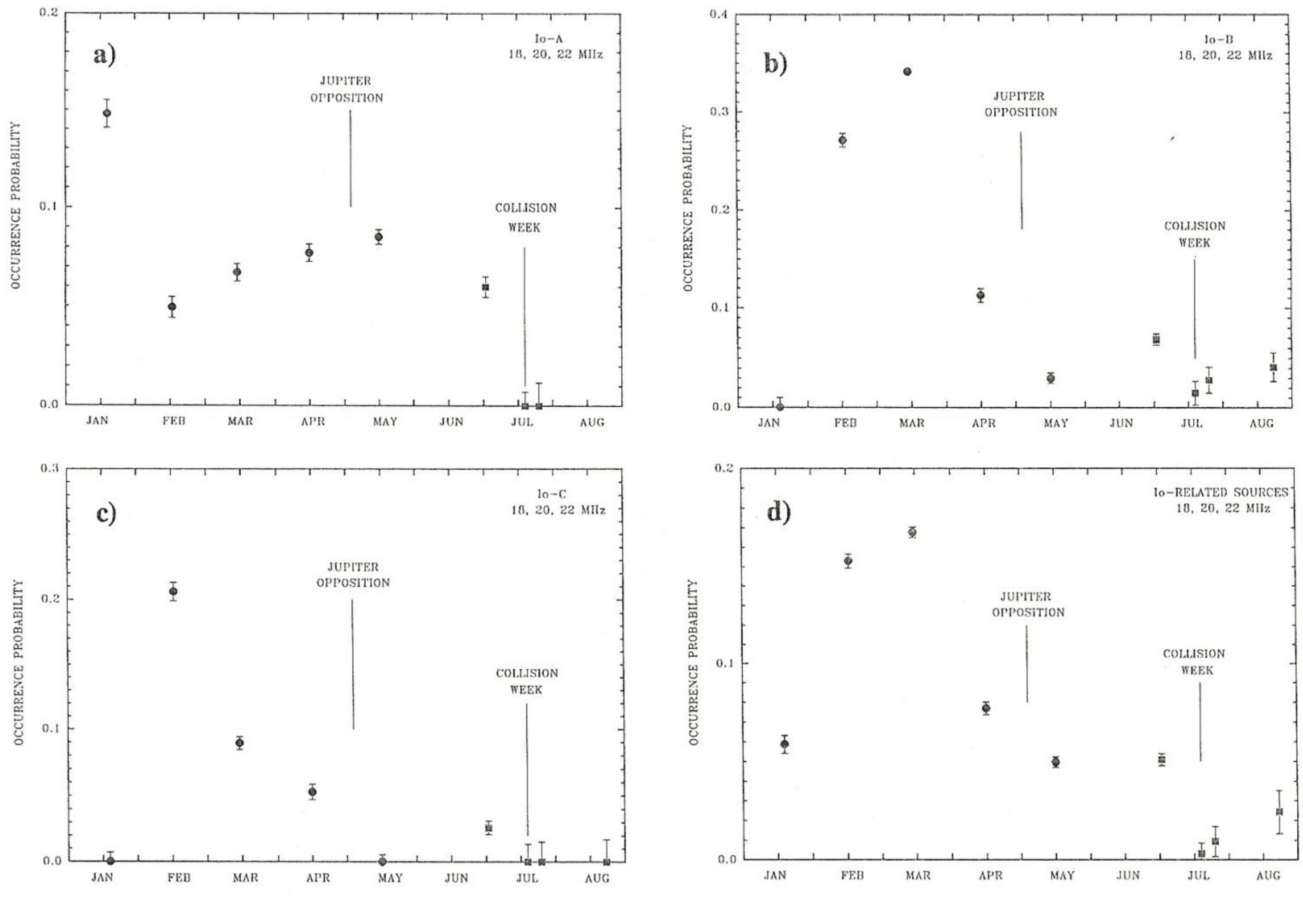
Plot of interference and the location of two bursts A (Fragment Q1) and B (Fragment Q2) received on July 20 at UFRO



Search for enhancement of emission from the known decametric sources

Plots of the Occurrence Probability (OP) for the Io-related sources (18, 20 and 22 MHz) for 1994 including the week of the collision.

The OP shows no enhancement during the week of the collision.



Publications reporting results of the observations of the decametric emission during the collision of comet S-L 9

Publications reporting no detection of emission from impacts

- Search for effects of comet S-L 9 fragments impacts on low radio frequency emission from Jupiter

  T.D. Carr, F. Reyes, L. Garcia , W. B. Greenman, J. Levy, C. A. Higgins, J. M. De Buizer, J. May, J Aparici, H. Alvarez, F. Olmos, J. A. Phillips T. Clark and S. Padin. Earth, Moon and Planets, 66, 31-48, 1994.

- Results of decametric monitoring of the comet collision with Jupiter

  T.D. Carr, F. Reyes, J. A. Phillips, J. May, L. Wang, J Aparici, H. Alvarez, F. Olmos, L. Garcia, J. M. De Buizer, W. B. Greenman, T. Clark, J. Levy, S. Padin, and C. A. Higgins . GRL, Vol. 22, No. 13, pages 1785-1788, July 1,1995.

- Traversal of comet SL-9 though the Jovian magnetosphere and impact with Jupiter: Radio upper limits

  Desch M. D., M. L. Kaiser, W. M. Farrell, R. J. MacDowall and R. G. Stone. . GRL, 22, 1781-1784, 1995

- Limits on decametric radiation from the Shoemaker-Levy 9 impacts on Jupiter.

  Kellogg P. J., K. Goetz, S. J. Monson and S.D. Bale. Ap. J., 484:432-438, July 20 1997

Publications reporting detection of emission from impacts

- Decametric bursts caused by the fragment S of comet SL-9

  Zhang X-Z, h. Wang, J-H Du and Z-K Wang. Earth, Moon and Planets, 66, 49-52, 1994

- Enhancements of Jovian decameter radiations after the Shoemaker Levy 9 comet crash event in 1994

  Oya H. , Step GBRSC News, Vol 5, No. 3, 9, 1995

A summary

- From the observations made by the UFRO group, the affiliated stations and the data provided by other stations, we concluded that no decametric emission was detected that can be attributed to the collision of the comet.
- Several stations detected bursts of the normal Jovian decametric emission
- Therefore, we could not confirm the emission reported by the Japanese and the Chinese groups.