Lecture for summer students
July 1971

US/GRBK/

RADIO STARS

R. M. Hjellming

Since about 1890 people have been trying to detect radio emission from stars, beginning with our own Sun. However, it was not until the 1940's that Reber, Southworth, and Hey independently detected radio emission from the Sun. Only during the last decade have any other radio stars been discovered. Between the 1940's and the early 1960's, radio astronomers had the habit of calling any new radio source a radio star. However, the data eventually showed that in all cases these sources were not single gravitationally bound bodies, as are all stars, by definition.

To appreciate the problem of detecting radio stars, let us consider the simple relationship between flux density, S_ν (in flux units, $10^{-26}\mathrm{Wm}^{-2}\mathrm{Hz}^{-1}$) and brightness temperature, T_B (in °K) for a uniform source of solid angle Ω_s ($= \pi\theta^2/4$ where θ is an equivalent disc diameter):

$$S_\nu = \frac{T_B\ \theta^2}{1970\ \lambda^2} \qquad (1)$$

In equation (1) θ is measured in arcseconds.

One of the most sensitive radio instruments presently available is the NRAO interferometer for which the minimum detectable flux density is 0.003 flux units for eight hours of observing. Therefore, for a source to be detectable

$$S_\nu \gtrsim 0.003$$

and using equation (1)

$$T_B\ \theta^2 \gtrsim 6\lambda^2\ , \qquad (2)$$

or

$$\left.\begin{aligned} T_B\ \theta^2 &\gtrsim 81 \text{ at } 3.7 \text{ cm} \\ T_B\ \theta^2 &\gtrsim 730 \text{ at } 11.1 \text{ cm} \end{aligned}\right. \qquad (3)$$

The optical sizes of the stars with the largest apparent diameters (the red supergiants) are at the most 0."05, hence for these one needs

$$T_B \gtrsim 32{,}000°K \quad \text{at} \quad 3.7 \text{ cm}$$

$$T_B \gtrsim 292{,}000°K \quad \text{at} \quad 11.1 \text{ cm}$$

Normal process on the surfaces of stars easily produce $T_B \lesssim 10^6 °K$, but it is difficult to produce larger values of T_B.

Some processes with larger T_B are known on the surface of the Sun

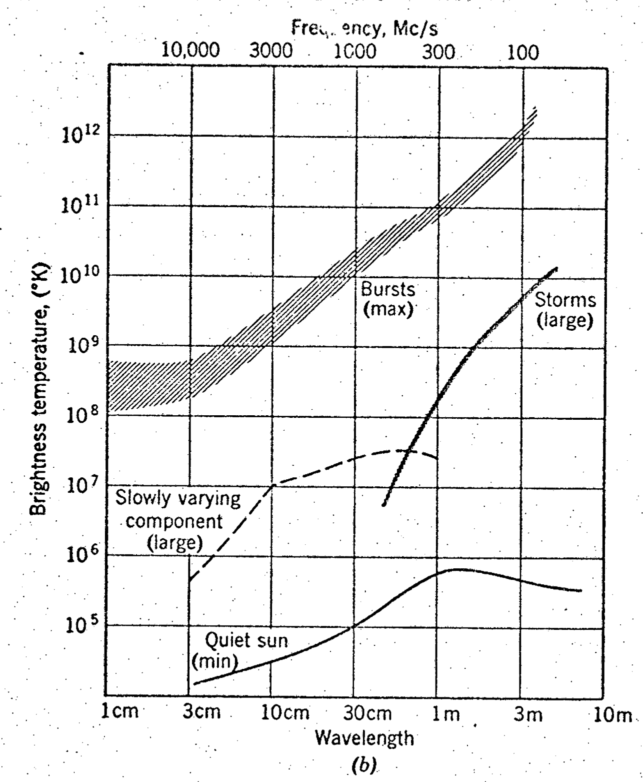


Fig. 1–1(b) The spectra of different components of solar radio emission, plotted in terms of brightness temperature. To calculate the brightness temperature, the source area is assumed to be as follows: the optical disk for the quiet sun; the sunspot area for the slowly varying component; and estimated mean areas based upon available observations for the bursts and storms (After Smerd 1964a).

The above figure shows the brightness temperatures for some of the major types of radio emission for the Sun.

Quiet Sun - chromosphere and coronal thermal emission

Slowly varying component - radio emission associated with sunspots or plages

Storms - non-thermal emission with time scales of hours to days. At sunspot maximum, in progress about 10% of the time

Radio bursts - short lived non-thermal events with time scales of a few minutes to hours.

Unfortunately, the quiet Sun at 10 cm could be seen only if closer than 0.07 pc, the slowly varying component could be seen only at less than 0.1 pc, and very strong bursts could be seen only within 2.5 pc.

The nearest star, ProximaCentauri, is only 1.3 pc away. You thus can see that only unusual processes are likely to produce a radio star. The worst problem with stars is that θ is always rather small, hence it takes a fantastic T_B to make up for this.

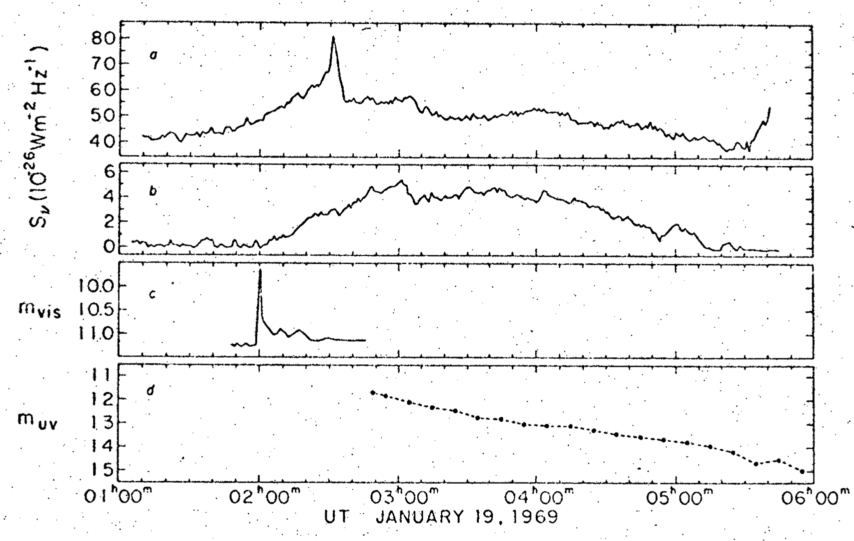
Despite all this, there are now five (and possibly 6) different types of radio stars.

FLARE STARS

Certain red dwarf stars are known to increase their brightness radically for brief periods of time (typically a few hours). These objects are called flare stars, and the flares they exhibit could be more intense versions of the well known solar flares. Since the solar flares are accompanied by intense radio bursts, the possibility of detecting these flare stars led British and Australian radio astronomers to monitor them extensively in the last decade. During several thousand hours of observing time, these investigators have found several cases of simultaneous radio and optical flares for a few stars, notably UV CETI, YZ CANIS MINORIS, and V371 ORIONIS. These were the first true radio stars.

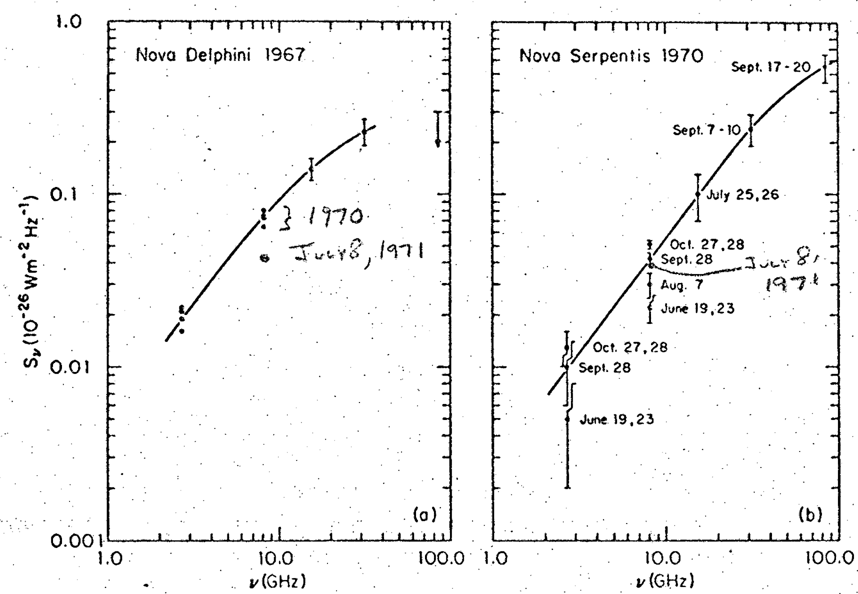
One of the best examples is the flare of YZ CANIS MINORIS shown below.

The interpretation of radio flare stars is still quite uncertain. There have been attempts to attribute the radio emission to shock waves moving through a corona, or to non-thermal flare phenomena like the radio bursts on the Sun. There is the difficulty, however, that the brightness temperatures are at least 10^{15}°K in some cases. This is a few orders of magnitude greater than has been observed on the Sun.



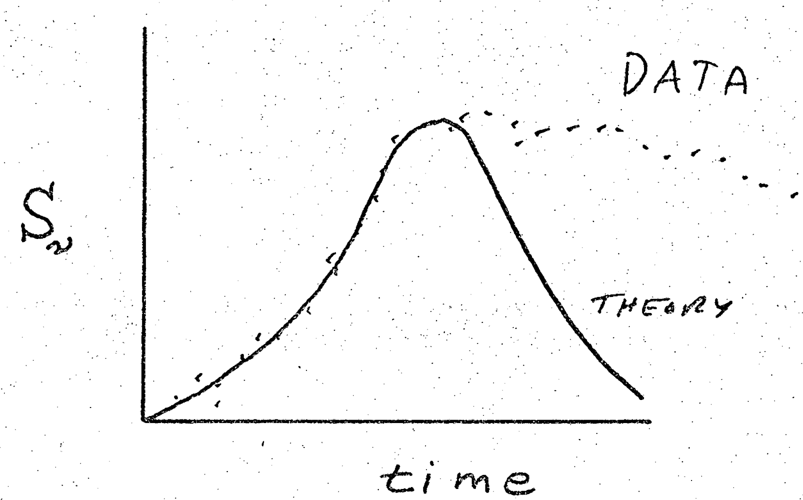
NOVAE

Some stars are subject to explosive activity in which they blow off part of their atmospheres. The m^a^ss which is ejected, perhaps 10^{-5} of their total mass, is thrown of violently with velocities which typically reach 1000 km/sec. These stars, called novae, were first detected as radio stars by myself and C. M. Wade in June 1970 with the Green Bank interferometer. Three novae: Nova Delphini 1967, Nova Serpentis 1970, and Nova Scuti 1970 have so far been detected.



Some of the data for two of the novae are shown above. Serpentis 1970 has been seen to increase in flux, level off, and start a decrease. Delphini 1967 has shown only a decrease in radio flux at 3.7 cm.

The promise of the nova data is that at first look it is incompatible with all known theories. There is little doubt that the radiation comes from thermal emission of the ionized matter cast from the star, but the evolution of the radio flux shows interesting features.



In particular, the rapid decrease expected when the density in the expanding shell drops rapidly is not seen. Probably either (1) re-ejection of new matter or (2) something holding parts of the shell together will be needed to fit the data.

RED SUPERGIANTS

This type of radio star must be placed in the maybe category. Kellerman and Pauliny-toth have reported a possible flare in the red supergiant called Betelguese (α ORIONIS). On February 21, 1966, they found a flux of (0.11 ± 0.03) f.u. at a wavelength of 1.9 cm. No signal was found, however, on eleven following nights.

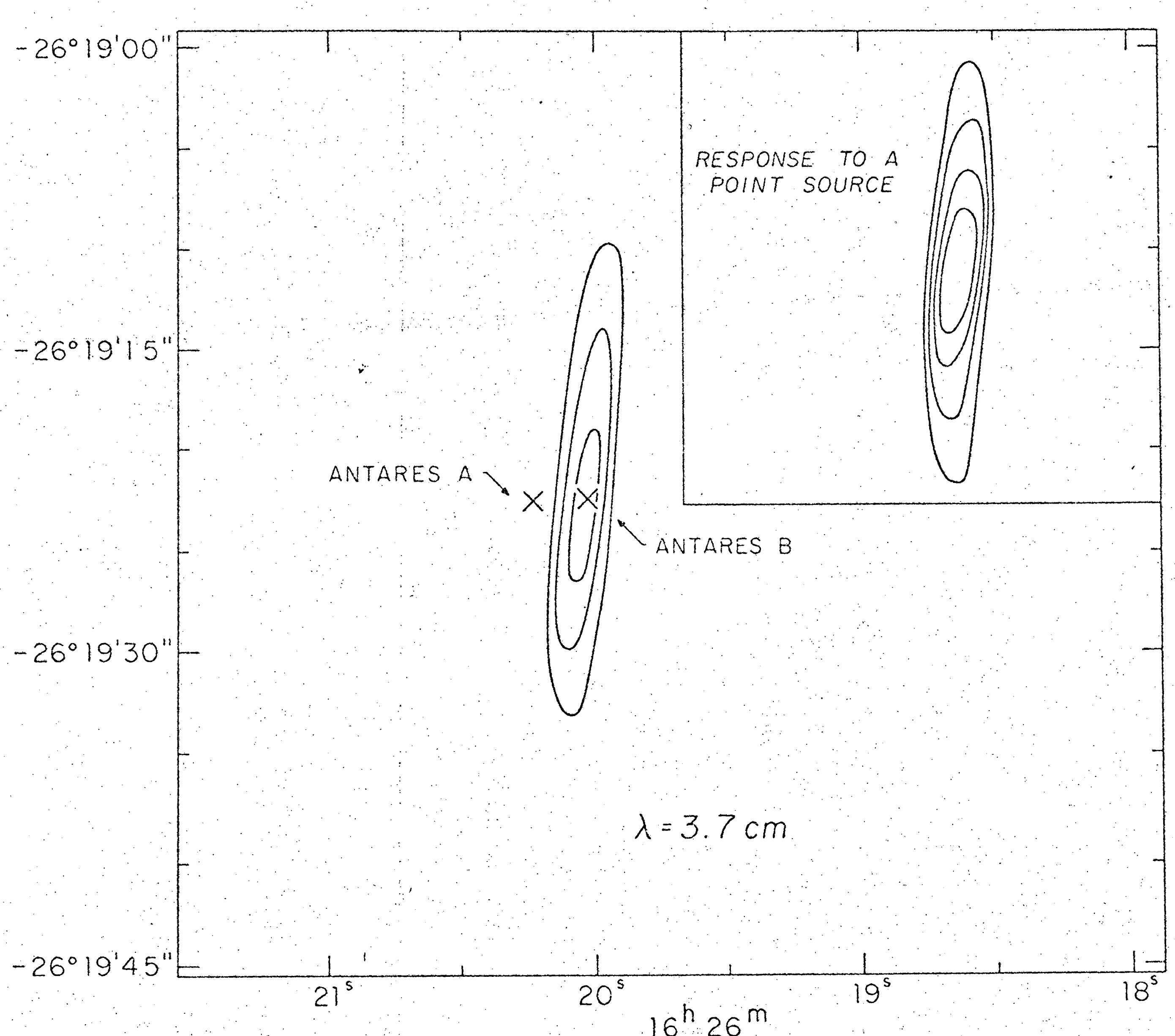
In addition, Seasquist reported a possible detection of Π AURIGAE, another red supergiant. However, again the result is not reproducible.

This non-reproducibility is the curse of this subject. We know now that every known radio star is variable and some are erratically variable, hence it may be difficult to obtain a particular flare on a particular star.

ANTARES B

Extensive observations of Antares, another red supergiant, have produced an unexpected result and a new type of radio star. Observations at 11.1 cm by myself and C. M. Wade on the NRAO interferometer have shown that in March, June and November 1970, Antares had a flux density of 0.005 ± 0.001 flux units. In June the flux at 3.7 cm was less than 0.003 f.n. On June 1, 1971 the Antares radio source was "flaring" at 3.7 cm to a level of $0.011 \pm .002$ f.u. A month later it was again less than 0.005 f.u. at this wave-length.

The surprise inherent in this data was that the radio source was not Antares A. the red supergiant, but rather was Antares B, a B3V blue companion 3".2 from the supergiant. The next page shows a 3.7 cm map of the source proving this.


-26°19'00"
-26°19'15"
-26°19'30"
-26°19'45"
RESPONSE TO A POINT SOURCE
ANTARES A
ANTARES B
λ = 3.7 cm
21s
20s
19s
18s
16h 26m

Whereas a red supergiant is very large, a B3V star is very small. Hence fantastic brightness temperatures are probably needed to produce the radio emission.

The variable radio source may also be related to a long known optical anomaly of the blue star: sharp forbidden emission lines of FeII and NiII with no other emission lines. This is physically very hard to explain because anything that excites these lines should excite hydrogen lines.

The answer to both anomalies seems to be unusual particle steaming in the atmosphere of the B star.

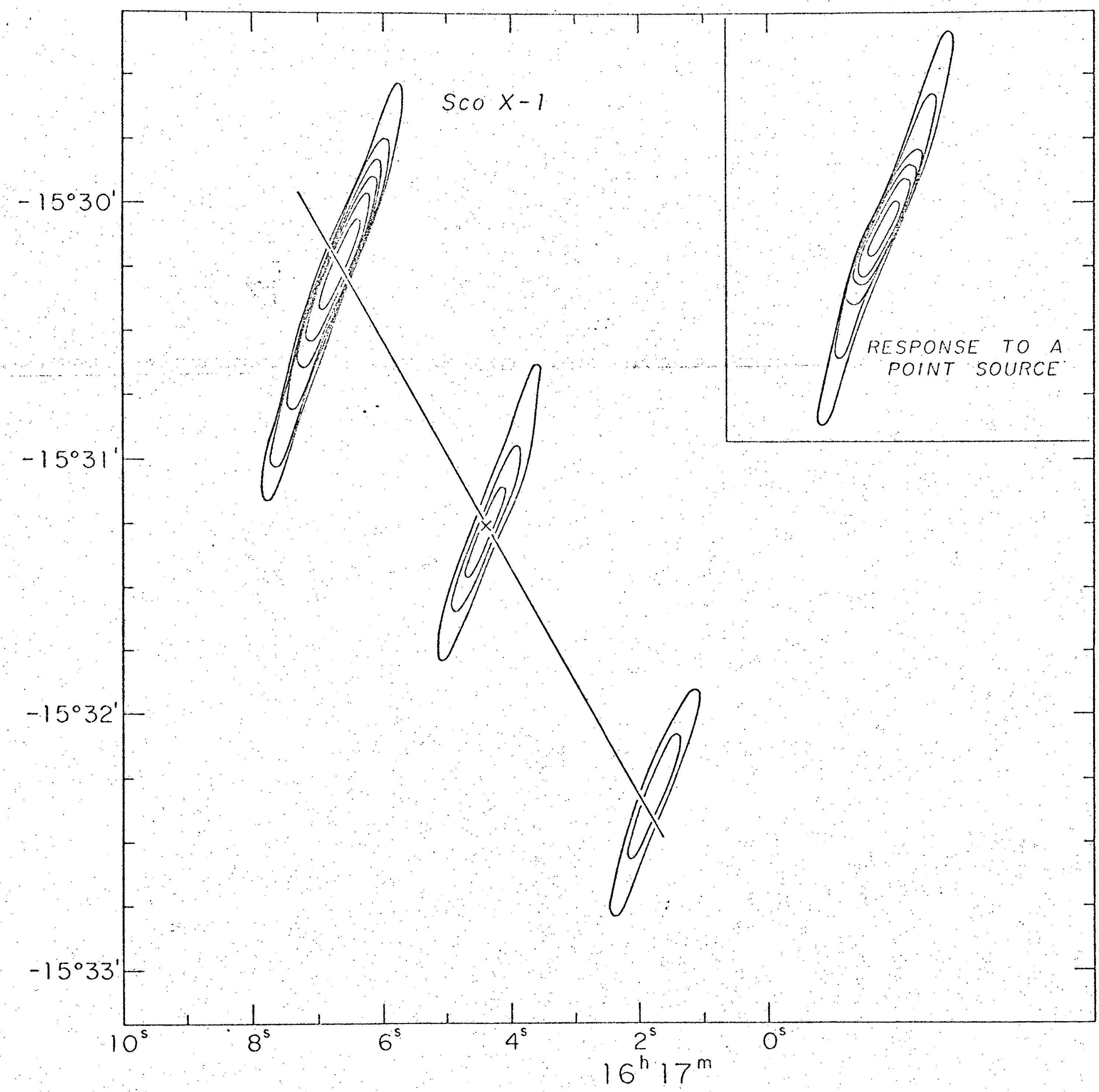
PULSARS

Pulsars are true radio stars. Because they have been a subject of special lectures this summer I will not discuss them.

X-RAY STARS

One of the most interesting developments of the last year is the coupling between X-ray astronomy and radio astronomy because of the fact that many X-ray sources are radio stars.

It all began with Sco X-1. In 1968 Andrew and Purton found it was a radio source and in 1969 Ables obtained data indicating it was a variable source. I and C. M. Wade entered the subject last year and have had a great deal of fun since then. The first thing we found, by using an interferometer which could accurately place radiation in the field of view, was that Sco X-1 is a triple radio source with the components arranged in a line. The next page shows a map of the source. This is reminiscent of one of the major unsolved phenomena in radio astronomy: why do double sources tend to be arranged on opposite sides of interesting objects.



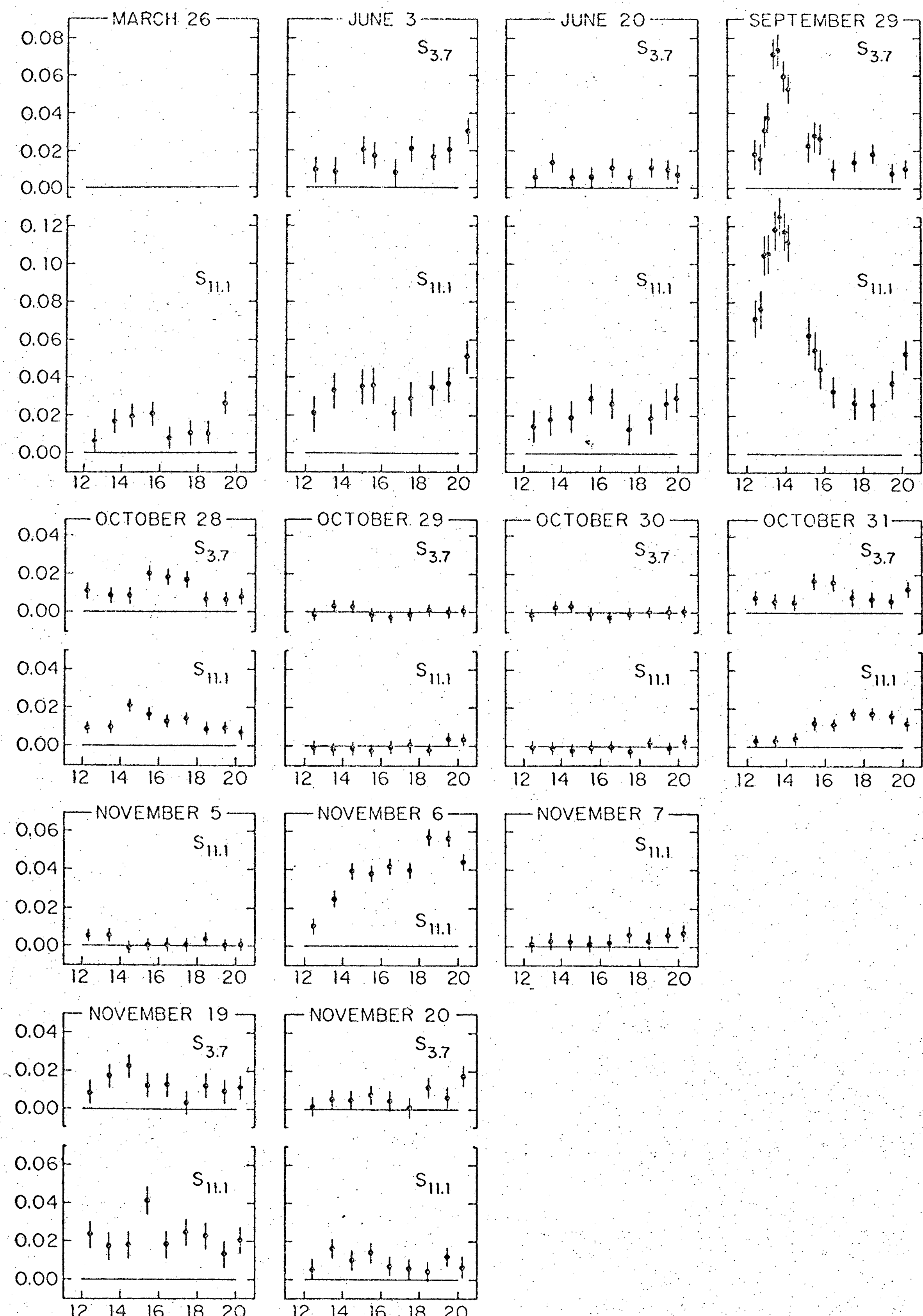
Indeed the central source sits exactly on the peculiar star identified as the X-ray source. Furthermore, the central source varies in flux by as much as two orders of magnitude in a few hours. Nobody yet understands this radio source, which appears to be non-thermal with a very variable spectral index.

Some pages of data on the time variations of this source follow.

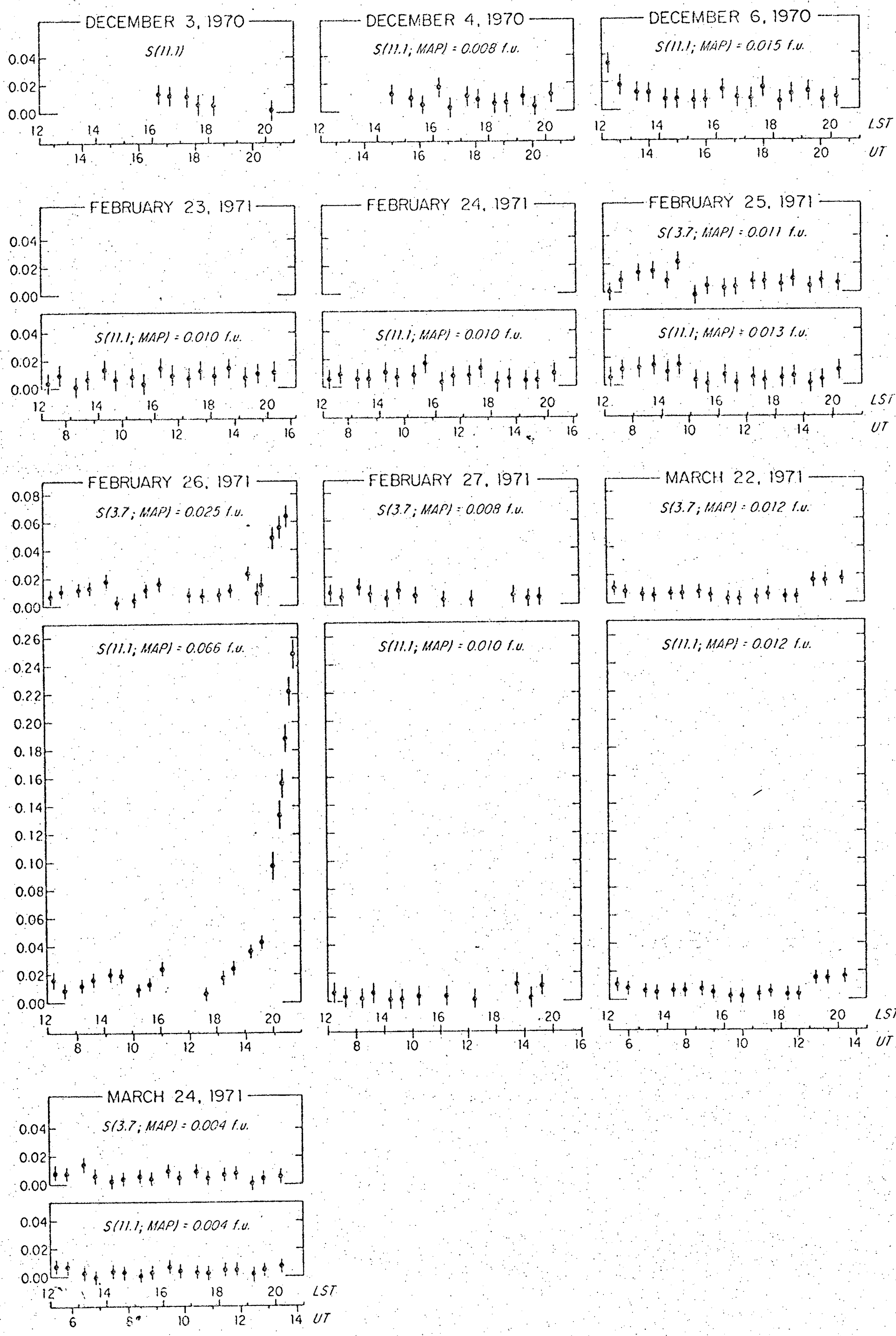
During the last month we have followed the clue of the variable radio star to find other X-ray stars. We have succeeded in finding one object in a beautiful Sco X-1-like flare: GX17+2. The map of this source and the proof of variation are shown in figures below.

A third X-ray source Ctg X-1, has been detected as a different type of variable radio star. It was not detectable before April 28, 1971, but was a steady radio source for a space of three weeks in May. The map of this source is also shown below.

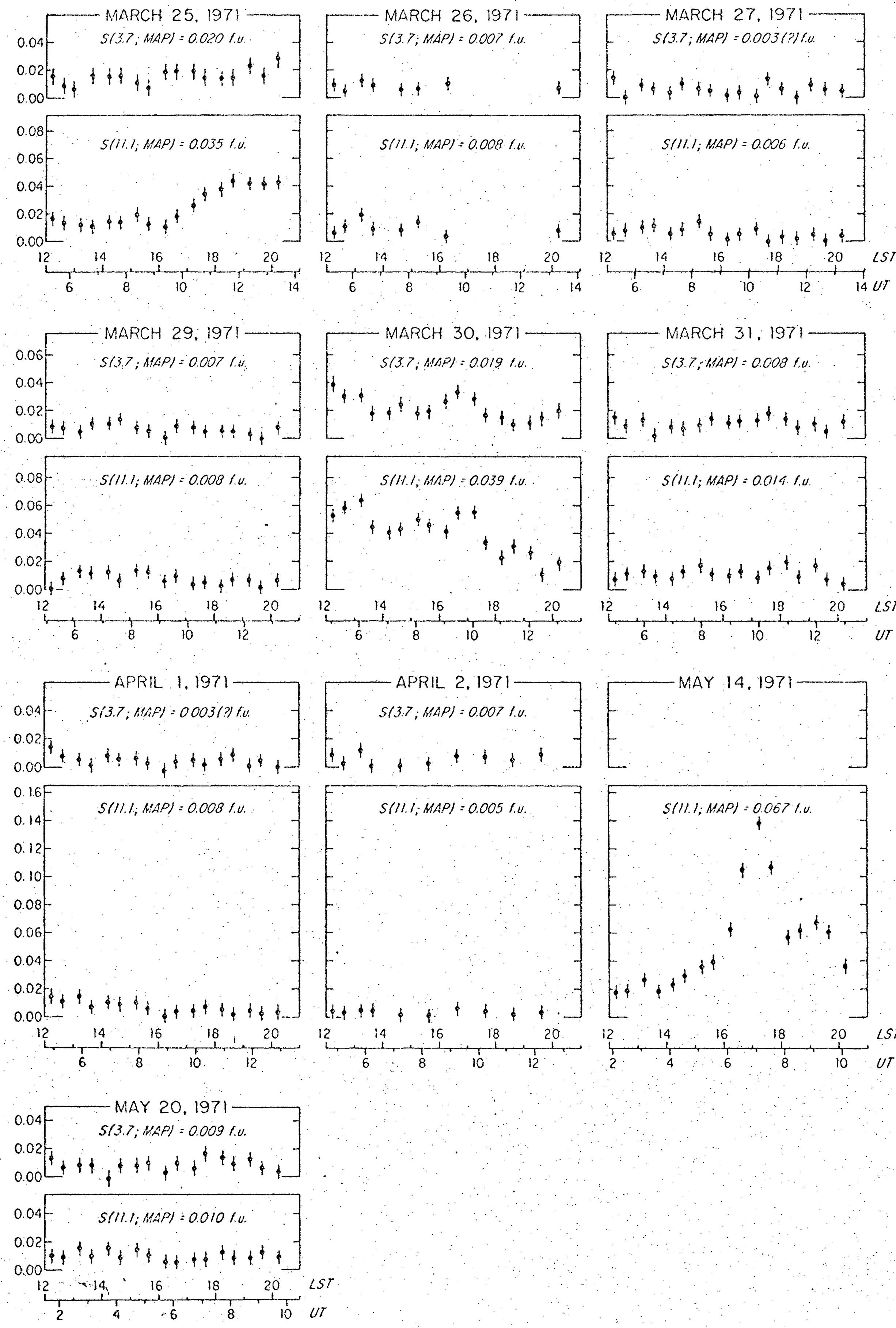
Sco X-1 Central Component

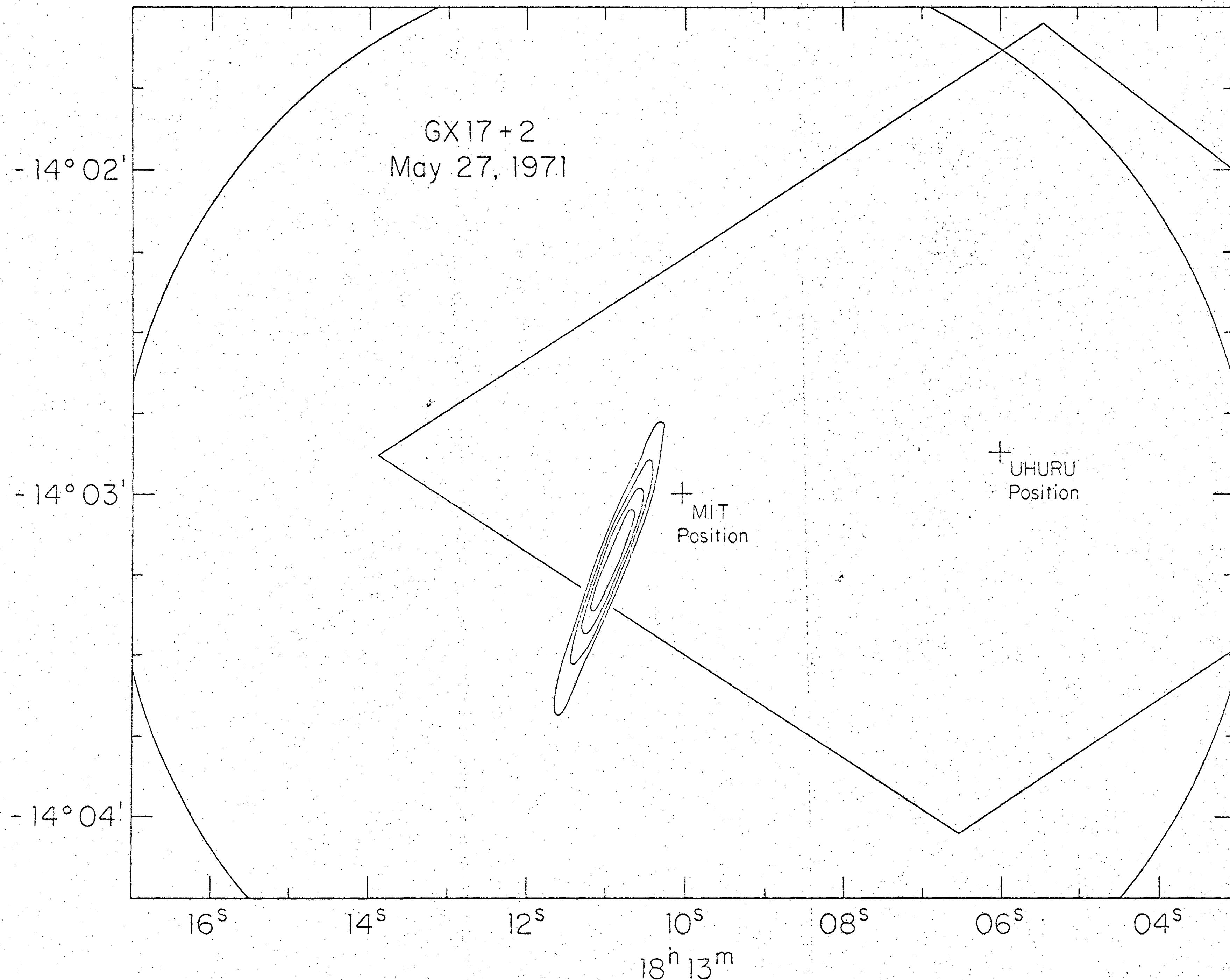


Sco X-1 Central Component

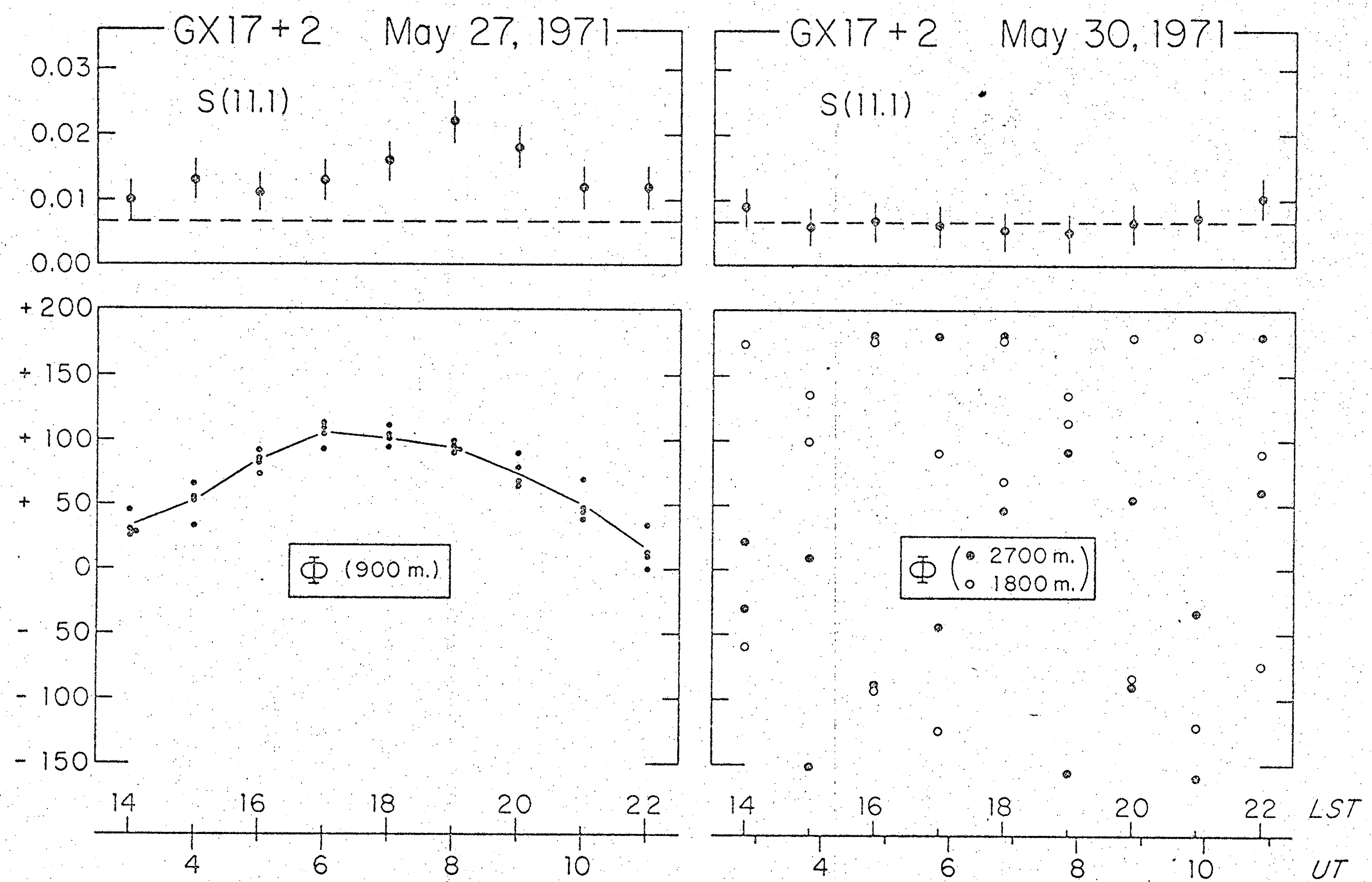


Sco X-1 Central Component

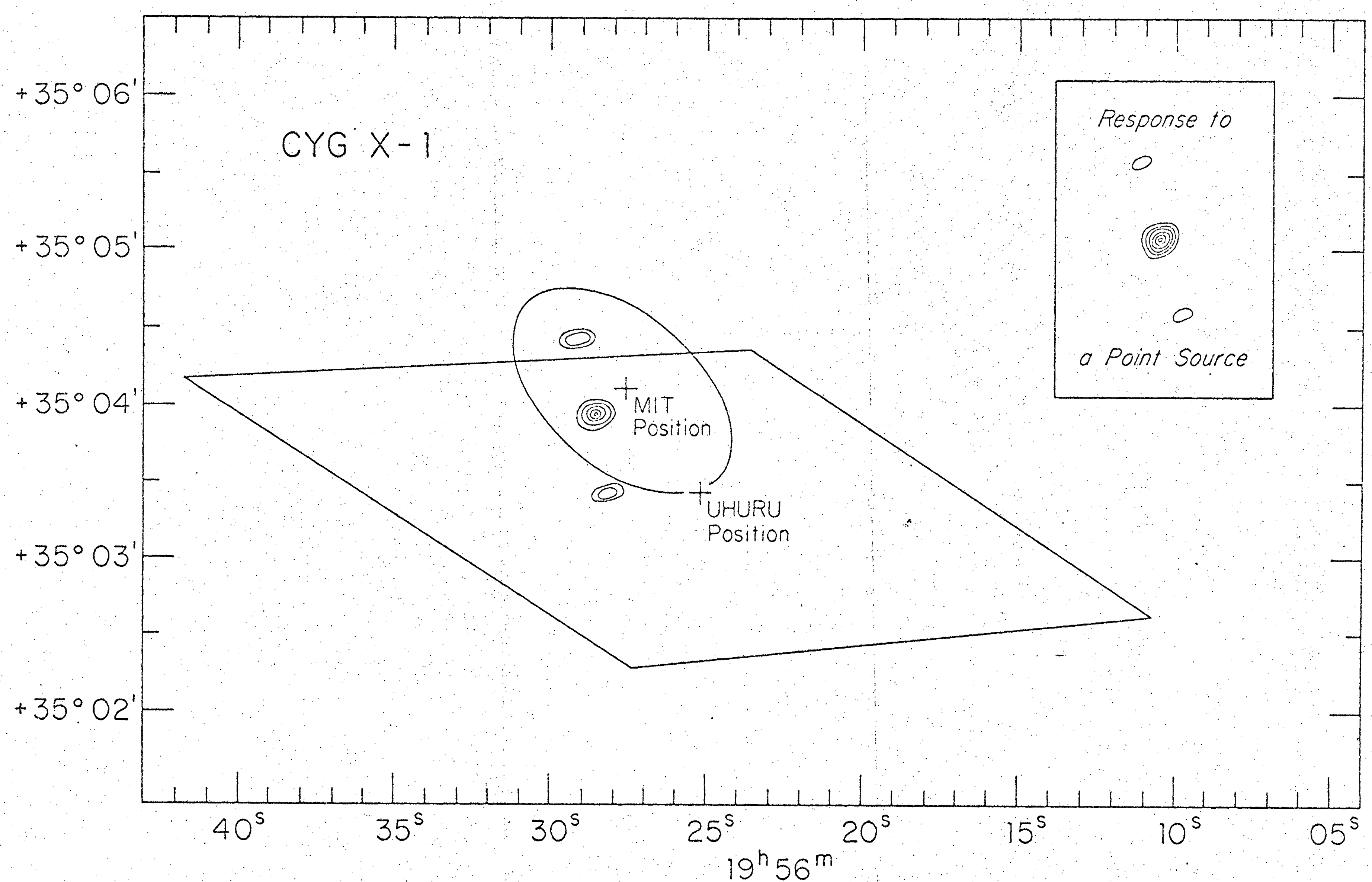




GX17+2
May 27, 1971
-14° 02'
-14° 03'
-14° 04'
MIT Position
UHURU Position
16^s 14^s 12^s 10^s 08^s 06^s 04^s
18^h 13^m



GX17+2 May 27, 1971
GX17+2 May 30, 1971
S(11.1)
S(11.1)
0.03
0.02
0.01
0.00
+200
+150
+100
+ 50
0
- 50
- 100
- 150
Φ (900 m.)
Φ (• 2700 m. ○ 1800 m.)
14
16
18
20
22
LST
4
6
8
10
UT


CYG X-1
Response to
a Point Source
MIT
Position
UHURU
Position
+35° 06'
+35° 05'
+35° 04'
+35° 03'
+35° 02'
40s
35s
30s
25s
20s
15s
10s
05s
19h 56m