FIRST INTERFEROMETRIC OBSERVATIONS WITH ARC-SEC. RESOLUTION OF SOLAR RADIO BURSTS AT MILLIMETER WAVELENGTHS

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ABSTRACT

We provide a brief description of the Berkeley-Maryland-Illinois Array (BIMA) in the context of solar observations. Specific areas of research that could be attempted using BIMA during the Max'91 period are outlined. Finally, some preliminary results of flare observations during March 1989 are presented.

The Astronomy Program of the University of Maryland has recently joined the Universities of California (Berkeley) and Illinois in a consortium to upgrade the Hat Creek millimeter-wave interferometer (to be known as the Berkeley-Illinois-Maryland Array, or BIMA). The improved array will become available during the coming Solar Maximum, and we will have guaranteed time for solar observing as part of the consortium. We plan to make quasi-dedicated observations for long periods (10-15 days at a time), depending on solar activity.

(i) **BIMA Array**

The Hat Creek millimeter interferometer presently consists of three 6-m diameter antennas which can be located at various stations along a T-shaped road-way which extends 300 m East-West and 200 m North-South. Current operation is in the 2.5 - 4 mm wavelength atmospheric window. The receivers employ cooled Schottky diode mixers. The receivers can be tuned by a solid state oscillator from 70 to 115 GHz. Retuning takes about 5 - 15 minutes. Both sidebands of the first mixer are received and are separated by phase switching of the local oscillators. Thus, two frequencies separated by 2.3 GHz can be observed simultaneously. One linear polarization is received. A quarter-wave plate to produce circular polarization around 90 GHz is available. The receiver, antenna and atmosphere contribute to the system temperature. Scaled to above the atmosphere, the temperature is typically 300 to 500 K SSB over most of the band, rising to about 1000 K at 115 GHz where the opacity is greater.

The BIMA consortium will expand this interferometer into a 6-element array with 15 baselines. Work is already in progress for this expansion, and it is expected to be completed in late 1990 or early 1991. This array with 15 baselines will permit us to produce synthesized snapshot maps of solar flares at one or more frequencies in the range 70 - 240 GHz. Before this expansion is completed, however, we shall use the instrument as a 3-element interferometer. This will be useful to find the positions of strongest burst sources with temporal resolution $\lesssim$ 0.1 sec and spatial resolution $\lesssim$ 1" arc. When the imaging instrument (6-element array) is completed, we will have a seventh antenna at our disposal which we plan to use at 3 or 4 wavelengths (20 mm, 10 mm, 3 mm and 1.3 mm) in order to obtain spectral information of mm burst sources.

ii) Science Objectives

The millimeter region has been perhaps the most under-utilized observing wavelength range in solar physics, due to the lack of telescopes which can match the temporal and spatial resolution available at other wavelengths. Millimeter wave observations are sensitive to both the highest-energy electrons in flares as well as to cool material in the chromosphere. Since we have only 3 antennas available at the present time, we shall concentrate on studies of flares.

ii (a) Flare Physics

Highly energetic particles accelerated in flares radiate strongly at millimeter wavelengths: in particular, since gamma-ray imaging is presently difficult, a millimeter array is the only method of imaging the most energetic particles in flares, and we propose many important studies using this fact. Using high time ($\lesssim$ 0.1 sec) and spatial ($\lesssim$ 1") resolution, we will study particle acceleration in the impulsive phase, and the location of acceleration region in relation to other flare features. In gamma ray-mm wave flares recent evidence (from Solar Maximum Mission and mm wave observations) has demonstrated that electrons and protons are accelerated almost simultaneously to very high energies. In particular, electrons attain energies of 10 to 100 MeV within one or two seconds of flare onset, and emit both mm waves and continuum gamma rays of high intensity. This continuum radiation is accompanied by nuclear gamma ray lines at energies less than ~ 10 MeV due to protons, and neutrons are somtimes detected at Earth (Chupp, E.L., Ann. Rev. Astr. Ap. 22, 359, 1984). At the present time there is no widely accepted explanation for this very rapid acceleration. Some argue that there must be a "first phase" process because of the very short time scale, possibly involving electric fields in double layers. Others argue that shock acceleration can act on short enough time scales (Decker, R.B., and Vlahos, L., Prompt Acceleration of Ions By Oblique Turbulent Shocks in Solar Flares, International Cosmic Ray Conference, La Jolla 1985). In the radio range, the spectral characteristic of gamma ray-mm wave flares is that the flux density increases with frequency.

We hope to add greatly to the understanding of prompt acceleration in flares using temporal and spatial resolution previously unavailable. Delays between gamma-ray and millimeter peaks will be studied in conjunction with spatial information on the location of the millimeter sources, which, along with information in microwaves, will allow us to investigate the propagation of energy from the corona to the chromosphere during the impulsive phase. We will also establish whether gamma-rays and millimeter-waves come from identical regions by studying the anisotropy of millimeter-wave flares on the disk.

ii (b) Electron Beams

In many flares, brightenings occur in Hα, EUV and even white light simultaneously with hard X-ray bursts. There is a controversy over the cause of these brightenings, whether due to electrons, protons, or an ion acoustic conduction front. Each method has problems: it is uncertain whether electrons are able to penetrate deeply enough into the dense atmosphere; we do not know how to accelerate an adequate number of protons in the required 1 s; and heat conduction by an ion acoustic front may be too slow (Dulk, G.A., Gary, D.E., Hjellming, R.M., and Kundu, M.R., Report of the Working Group on the Sun and Stars, Proc. NRAO Millimeter Array Workshop 1986).

Observations of mm waves can help answer these questions because they originate in the relevant region of the atmosphere, namely the low chromosphere, in contrast to cm waves which originate in the lower corona. If the mm wave emission in some flares is due to thermal bremsstrahlung from the heated plasma, it is relatively easy to relate radio wave brightness to the density-temperature structure in the heated region. The relative timing of mm wave vs. cm wave bursts should help distinguish among the possible causes.

iii) Preliminary Results From Interferometric Observations at 3 mm Wavelength

Using the presently available 3-element BIMA telescope we were able to observe the active region 5395, which produced an X-15 flare and many X- and M-class flares, during the period March 12-18, 1989 (the second half of its disk passage). For most of this time only one base line was available (because one receiver was not operational), and the weather was not good enough to measure the phase. Thus, positional data are not available. BIMA was in its widest configuration (spatial resolution ~ 1" arc), but the time resolution was only 10 seconds. With this system we observed several X- and M-class flares - all associated with optical Hα flares and/or microwave burst emission (as observed with the Owens Valley microwave inteferometer). The most striking result that has come out of these observations is that most millimeter bursts are spiky (that is unresolved with 10 sec time resolutions, see Fig. 1); there is a considerable amount of burst emission from sources of size < 1" arc. Three-base-line observations show that the source structure is not symmetric (Fig. 2). Corresponding to a typical microwave burst observed at OVRO with 3 sec time resolution with an impulsive phase followed by a post-burst, we observed a complex 3 mm burst with many spikes both during the impulsive and the post-burst phase (Fig. 1a). This suggests that at mm wavelengths we are really observing different flare kernels which brighten up sequentially, so that spatial structure is seen as time structure as schematically illustrated in Fig. 1c.. We have observed one spike corresponding to a hard X-ray spike (Fig. 3) and UV-emission (Fig. 3a) observed by the SMM-HXRBS and SMM-UVSP experiments. There is good correspondence between the two time profiles (within 10 sec time resolution); hard X-rays were observed up to 100 Kev. The power-law spectrum (Fig. 3b) is not particularly hard - somewhat softer than what is observed in γ-ray flares.

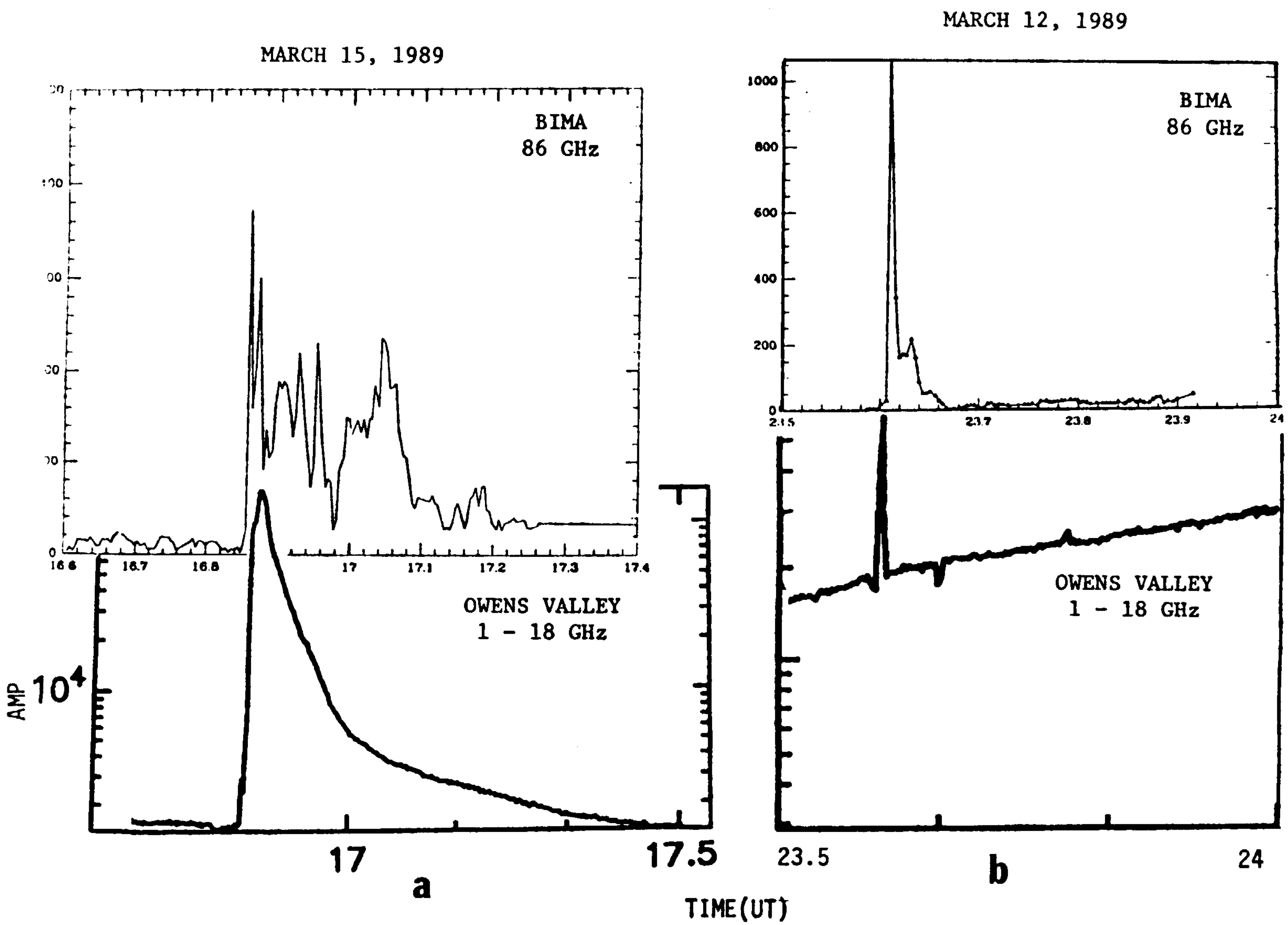

Fig. 1: With 1" arc spatial and 10 sec temporal resolution 3 mm bursts apppear as intense spikes - sometimes simple, sometimes complex. A significant part (probably a few percent) of the total flare emission at this wavelength appears to originate from kernels < 1" arc or < 700 km. This is the first direct measurement of such small scale structures in flaring regions. We believe that the flare kernel brightens up sequentially and appear as temporal structures.

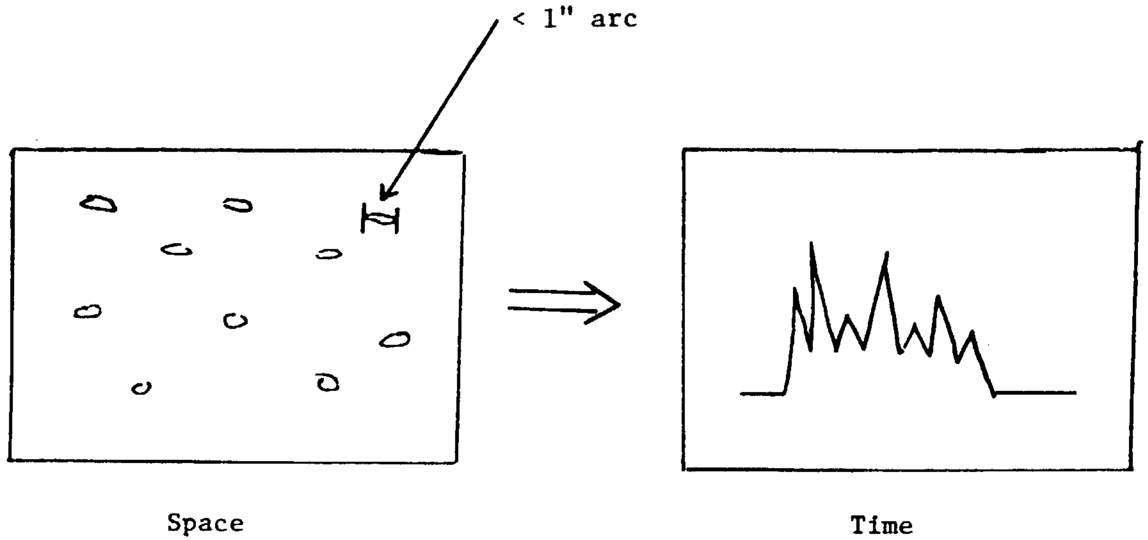

FIG. 1C

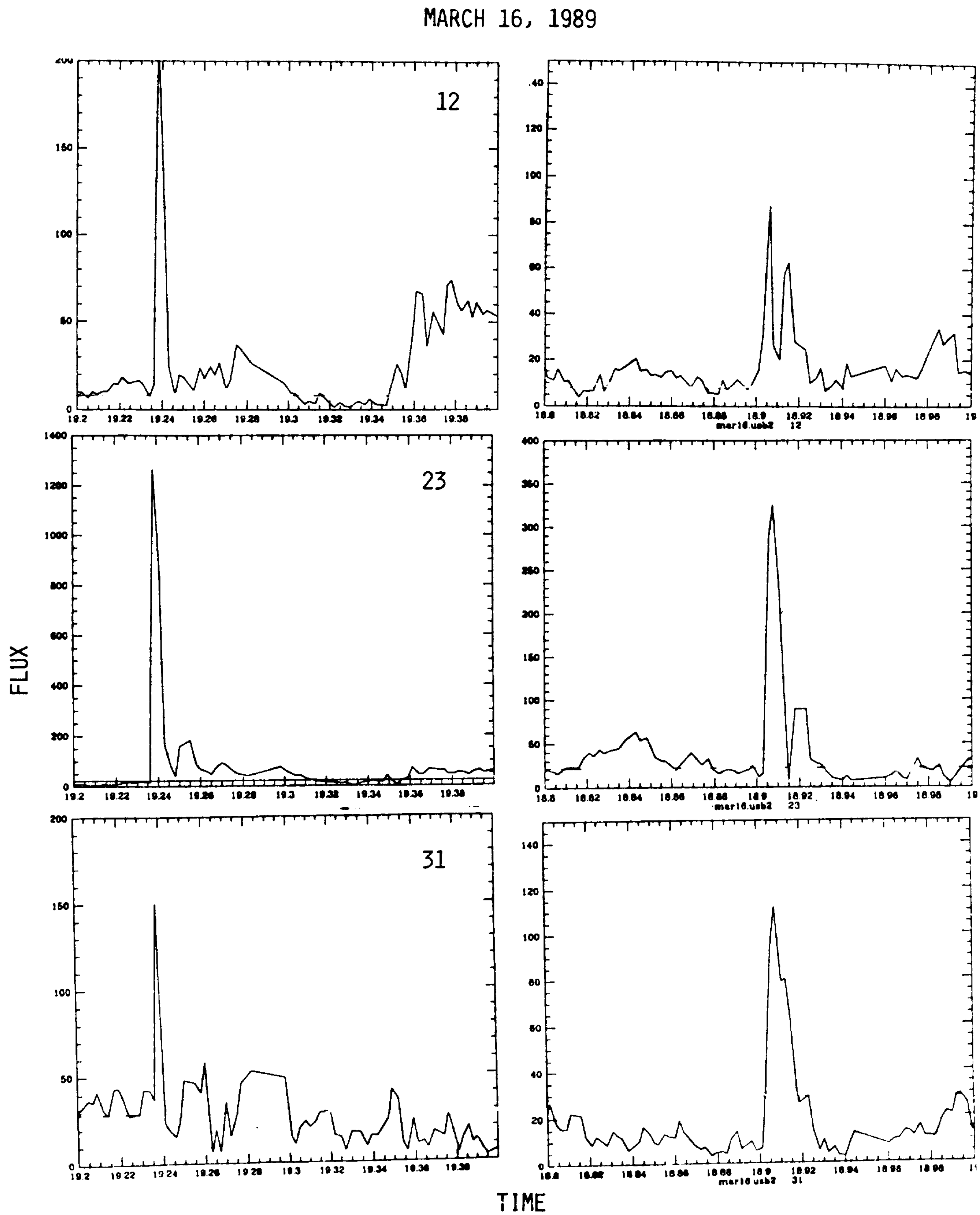

Fig.2 : Time profiles of two flares on March 16 1989 indicating assymmetry in the source. Note that the flux is larger by factors of 3 (right) and 10 (left) in the 2-3 base line compared to 1-2 and 3-1.

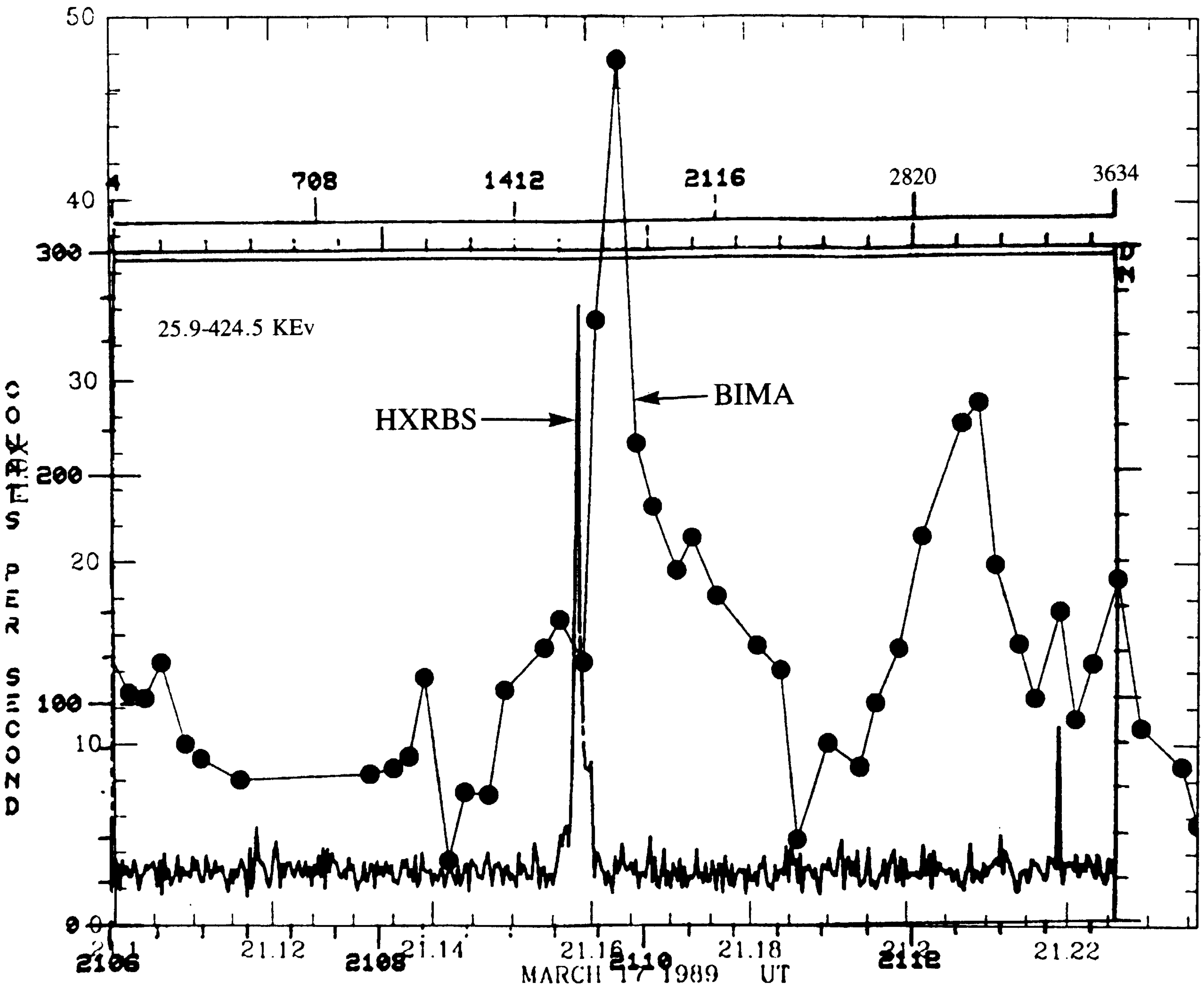

Fig.3 : Comparison between mm(BIMA) and SMM-HXRBS time profiles of March 17 1989 Flare. (Courtesy of R. Schwarts and B. Dennis for HXRBS data).

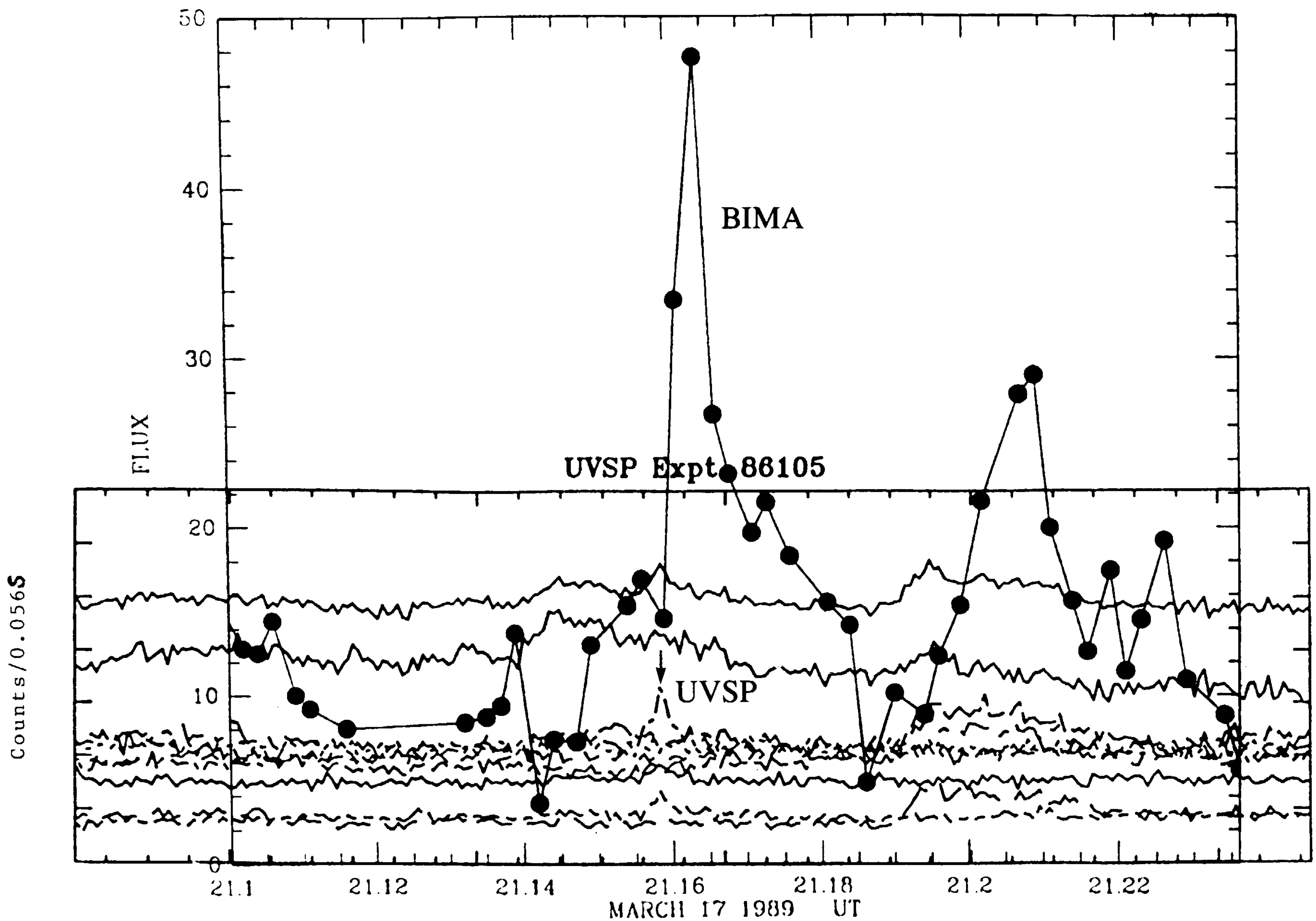

Fig.3a : Comparison between mm(BIMA) and UVSP time profiles for March 17 1989 Flare. (Courtesy of J. Gurman for UVSP data).

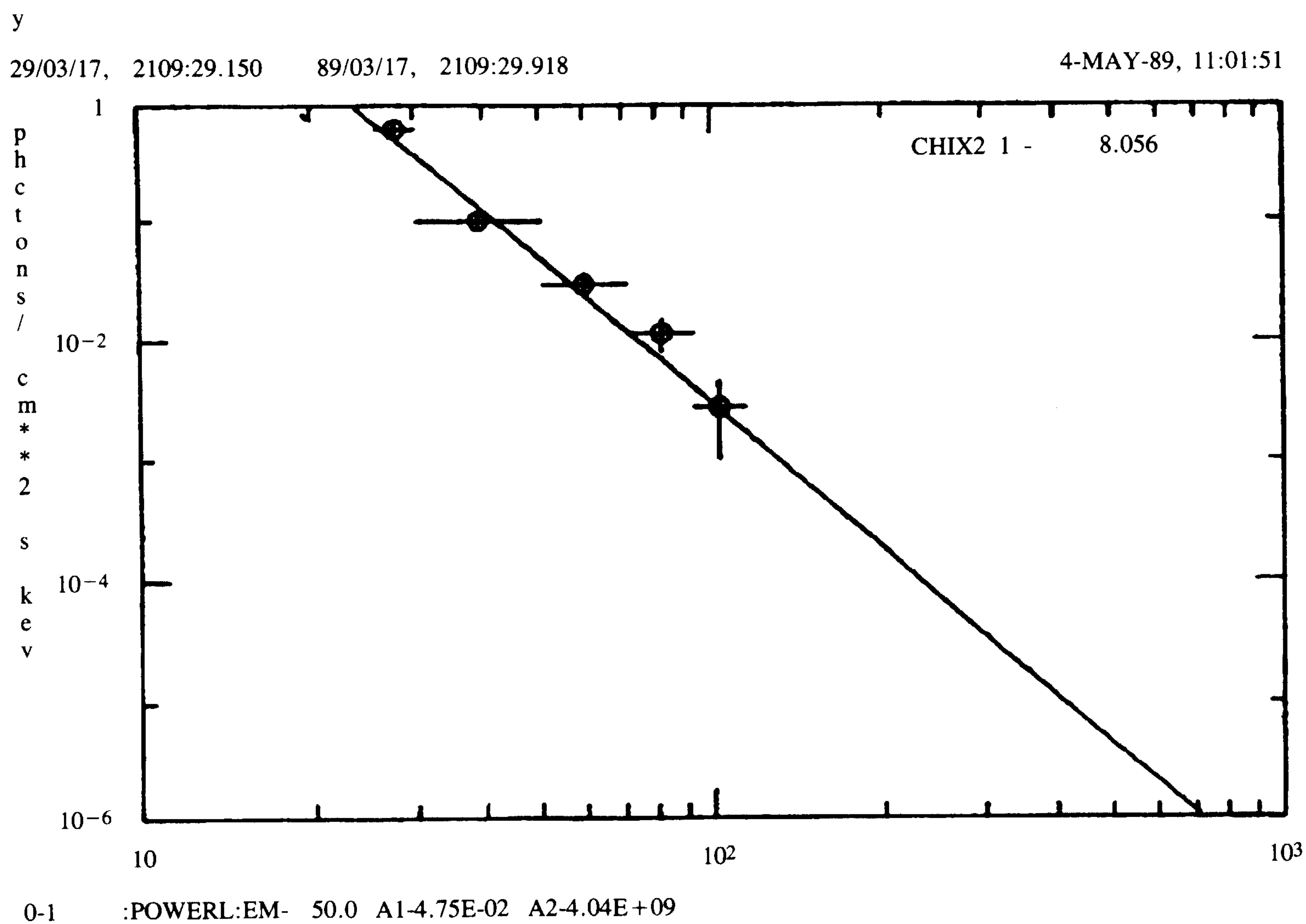

Fig.3b : Power spectrum of the March 17 1989 Flare from HXRBS.
(Courtesy of R. Schwartz and B. Dennis)