Microwave and (Hard) X-Ray Images of Solar Flares

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1. Source structure
2. Particle populations. Timescales
   - Pre-flare phase
   - "Hot thermal" imp. phase emission
   - "Impulsive" and "gradual" emission from nonthermal particles
3. Requirements for future observ.

HXR and μ-λ imaging in the 1980s

XR:	HXIS (SMM)	$h\nu \lesssim 30$ keV
	SXT (Hinotori)	$h\nu \lesssim 40$ keV

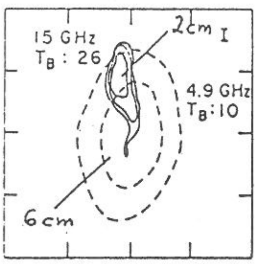
Microwaves:

1 D	Nagoya	35 GHz / 9 mm
	Nobeyama	17 GHz / 1.8 cm
	WSRT	5 GHz / 6 cm
2 D	VLA	23, 15, 5, 1.4 GHz / 1.3 - 21 cm

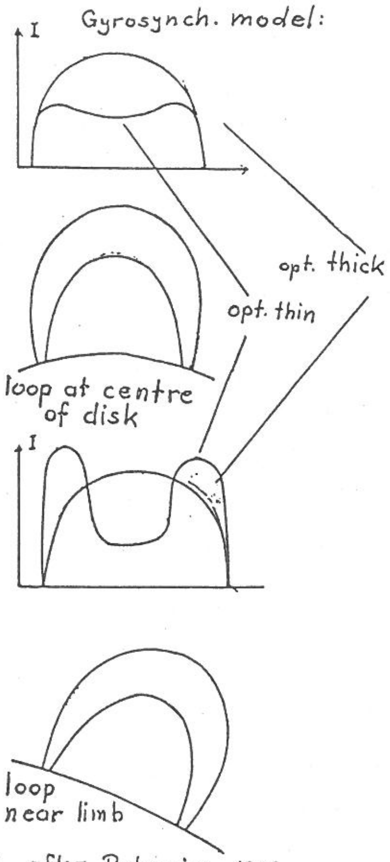
Shortcomings:

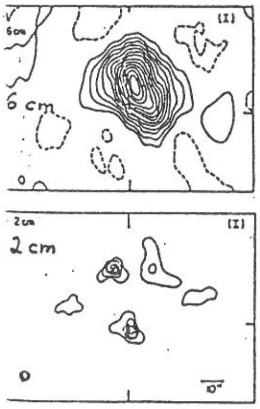
- XR images at low $h\nu$, integration $>$ 1s
- μ-λ integration $>$ 1s
  1 D
  weak sensitivity to ext. struct.
  time sharing with non-solar observations

Microwave structure of a flaring loop



Dulk, Bastian, Kane 1986





Shergaonkar, Kundu 1985

after Petrosian 1982
Alissandrakis, Preka 1984
Klein, Trottet 1984

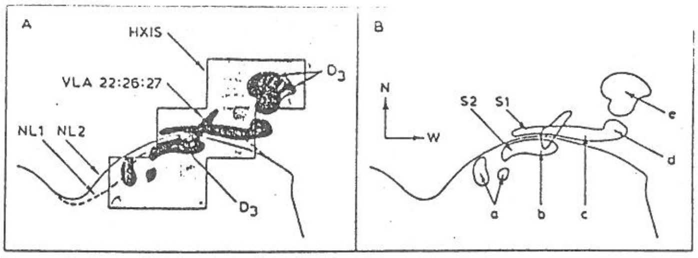


FIG. 3.—(*a*) Composite line drawing indicating various flare components: Hα flare kernels taken from Fig. 2*b*; the possible position of the neutral line (*NL2*), laterally shifted from the measured position (*NL1*) nowhere more than 2".5; outline of the VLA sour the time of peak 2 and the HXIS pixels *A*, *T*, and *B*; location of the He D_3 emission (the patch south of the neutral line being very weak Same as Fig. 3*a* showing only Hα kernels with the two central strands *S1* and *S2*, VLA source, and proposed neutral line. Arrows inc various locations *a* through *e* which are referred to in the text.

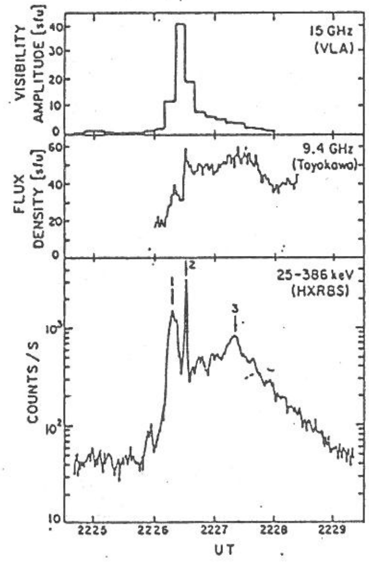
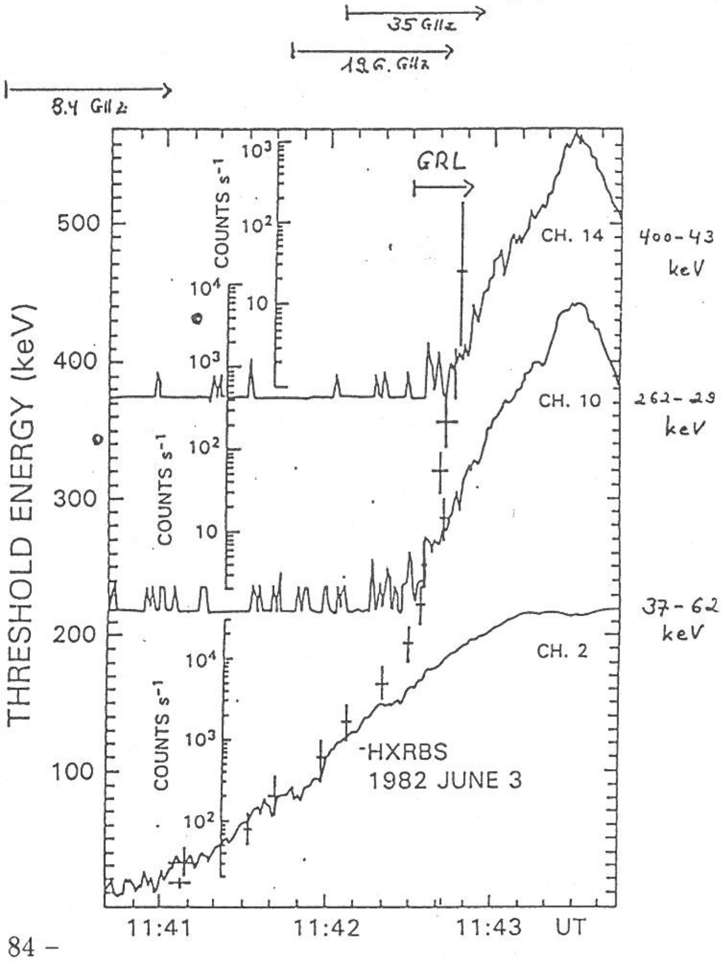
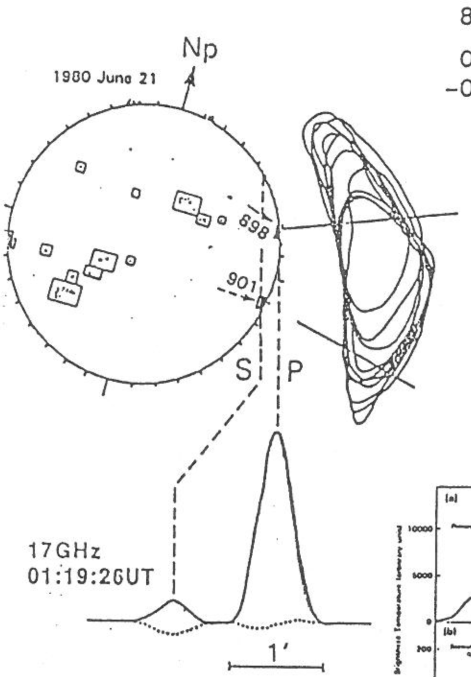
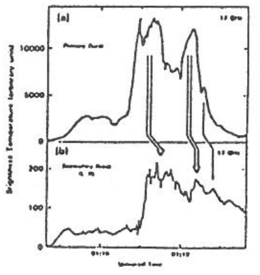


FIG. 4.—(*a*) Microwave visibility amplitude at 15 GHz (Stokes parameter *I*) on a baseline of 8".2 fringe spacing, hence catch whole microwave flare area. (*b*) Observed flux density at 9.4 GHz (Stokes parameter *I*). (*c*) 25–386 keV count rate as observed by H on *SMM*. The flare shows three peaks, labeled 1, 2, and 3.

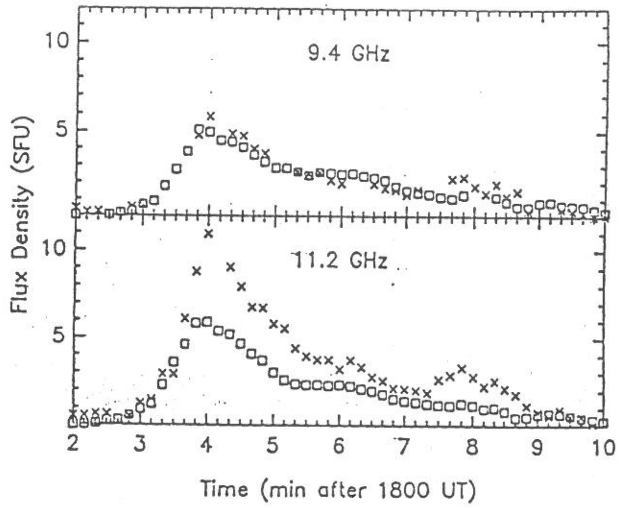
Hoyng et al. 1983



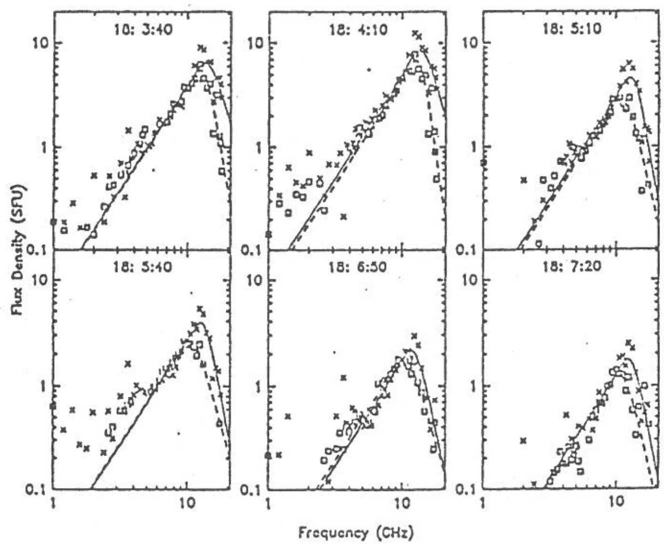




NAKAJIMA ET AL.



Hot thermal flare (cm-λ; OVRO)
$T_e \leq 8 \cdot 10^7$ K



Gary, Hurford 1988

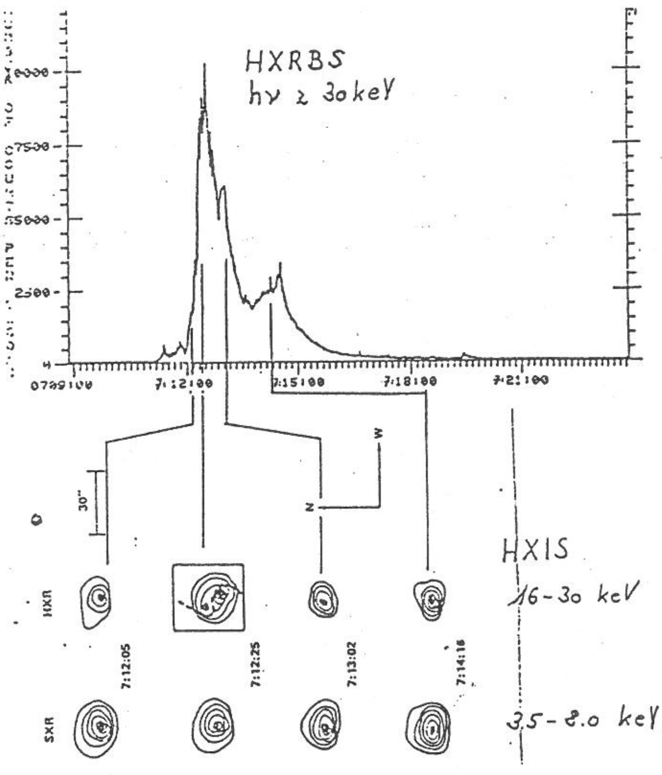
Hot thermal plasma

relation to NT particles ?

where ? when ?

Magnetic configuration
well confined
$\overset{?}{\Rightarrow}$ heating (Schmahl et al. 1990)

Plasma parameters
high density
$\overset{?}{\Rightarrow}$ heating (Tsuneta 1987)



Machado et al. 1988

Pre-flare phase ($\lesssim$ 60 min. before imp.)

Pre-heating (SXR, occas. cm-λ)

Precursors (SXR - Tappin 1990, occas. cm-λ)

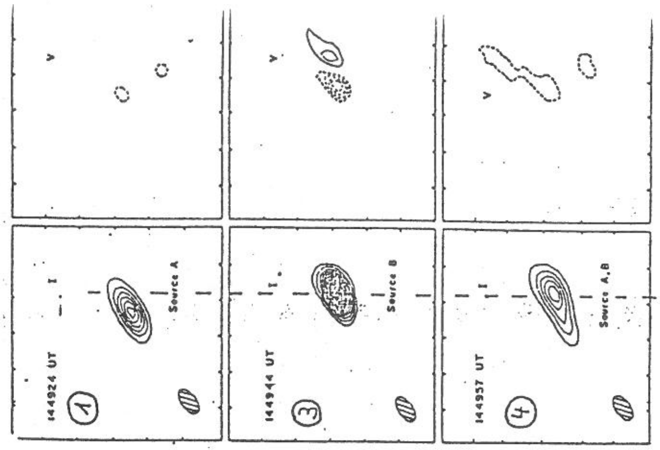
Flux emergence (changes in V occas. found in cm-λ)

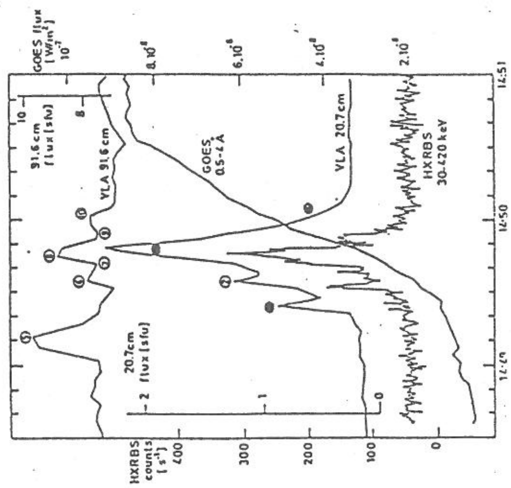
Nonthermal e^- (min. before imp. phase dm-λ; Benz et al. 1983)

Onset of the impulsive phase

1. Time delay low/high hν: pre-flash
2. Simult. rise low/high hν: flash

Different source structure (XR, cm-λ)





Hot thermal flar(e) (HXR - Hinotori)

$T_c \doteq 3-5 \cdot 10^7$ K

$n_e \sim 10^{11}$ cm^{-3}

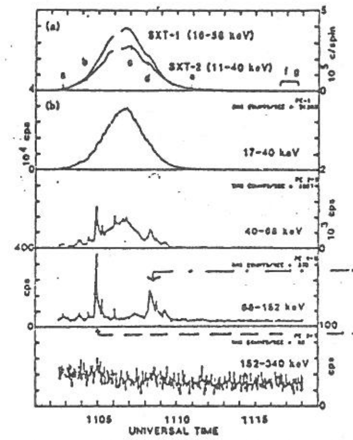
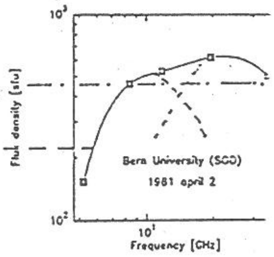
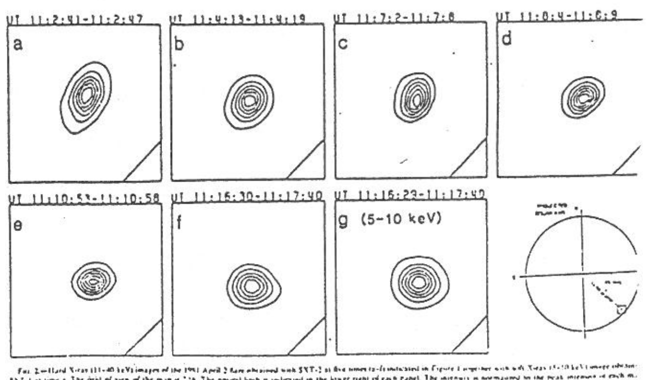
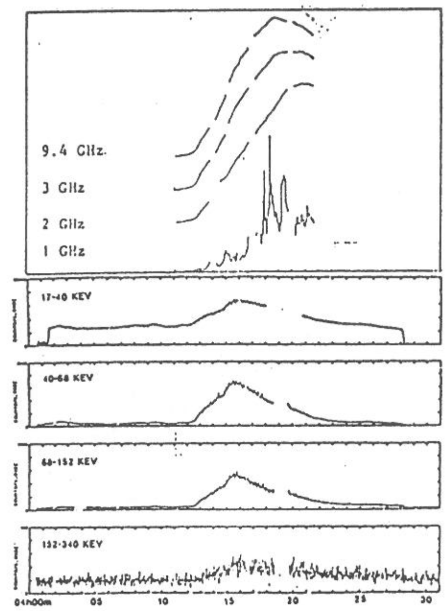
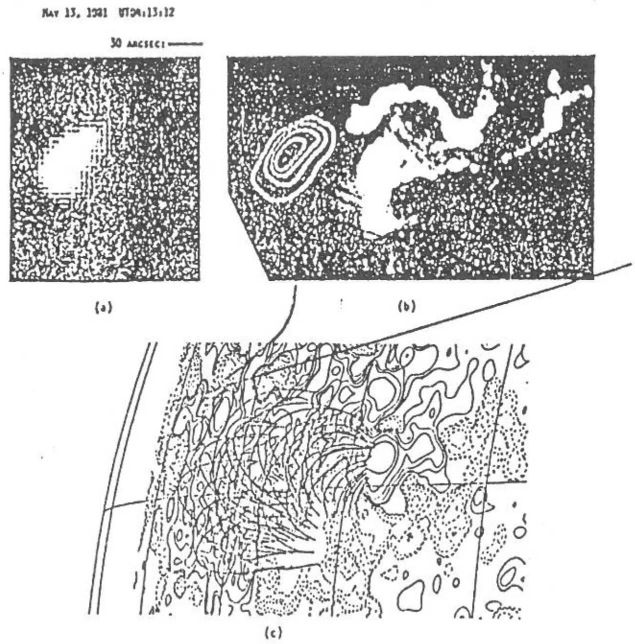


FIG. 1.—Hard X-ray time profiles of the 1981 April 2 flare as observed with the hard X-ray spectrometer on *Hinotori*. All data points are plotted with 1.0 s time resolution. Time profiles of the total event rates of the two hard X-ray telescopes (SXT-1 and 2) after integrating over one spin period (13.3 s) are also shown. SXT light curves are nearly the same as that of a 17–40 keV band (PC-1) of the spectrometer. Note that in bands above 68 keV, there is little excess photon flux above background level even around the intense peak with energies below 30 keV.









Bipolar structure in μ-wave burst sources
(Kattenberg & Allaart 1983)

A: narrow $< 10''$
bright $> 10^8$ K
rapid variation < 1 s (somet. < 0.1 s)
often several sources

B: broader, $\gtrsim 15''$
fainter $< 5 \cdot 10^7$ K
slowly evolving, delayed
often polarized

A, B have similar fluxes, i.e. they yield similar contributions to the disk-integrated flux.

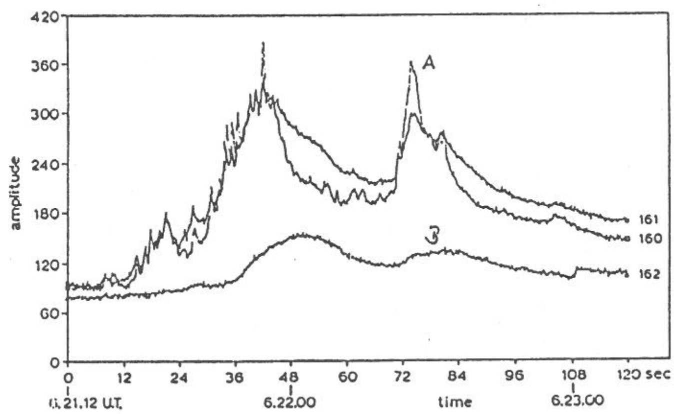


Fig. 6. Time profiles at three (one-dimensionally) adjacent locations in burst 2195

Summary: Imaging cm-λ / XR

1. Pre-flare
   current build-up; coronal $\vec{B}$;
   flux emergence
2. Onset impulsive phase
   TNT populations
3. Impulsive & "gradual" emission
   when: simultaneous / subsequent?
   causal relationship?
   where?
   Implication on acceleration, transpo
4. Rapid fluctuations (< 1 s)
   complex source structure $\rightarrow$
   complex spatial pattern of
   energy release?
5. Hot thermal populations / NT pop

COMPARISON OF MICROWAVE AND X-RAY IMAGES OF SOLAR FLARES

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Ever since the earliest observations of hard X-rays from solar flares, a close similarity of their time history with that of the microwave emission has been discovered. This stimulated the joint interpretation and extensive modelling of the emissions which are recognized as the most direct diagnostics of energetic electron populations in the solar atmosphere. The observational parameters which have been mostly exploited to test the models were global quantities integrated over the emitting source.

Imaging observations in both wavelength ranges have been carried out since ten years. Their role in mapping the structure of the emitting sources, the evolution of the flaring active region and the transport of energetic particles will be reviewed. However, X-ray and microwave imaging has suffered, so far, from different types of shortcomings. On the one hand, X-ray imaging was performed at relatively low energies, where the thermal flare plasma contaminates the emission. As the microwave emitting electrons are much more energetic, images in both ranges concerned different physical processes. Microwave observations, on the other hand, were carried out either with resolution in only one spatial dimension or, at least in the earliest attempts, with insufficient sensitivity to extended structures. Simultaneous observations with high temporal resolution (of the order of 1 second) have not been performed so far.

Combined observations with the Nobeyama radioheliograph and the hard X-ray telescope on bord the SOLAR A satellite will allow dedicated simultaneous mapping of flares in hard X-rays and microwaves with high time resolution. The temporal resolution will enable us for the first time to map the sources on timescales where significant differences between microwaves and hard X-rays have been shown to exist by former observations. These data will be a new tool for probing the acceleration and transport of energetic particles and for testing models developed in recent years. The talk will aim at giving an outline of these tools, in discussing the evolution of the source structures from the pre-flare to the post-impulsive phase, and the evidence for thermal and nonthermal particle distributions during flares. The potential influence of absorption at high microwave frequencies and the importance of multiple-wavelength microwave observations will be stressed.