Sub-THz (or super-mm) observations of solar flares

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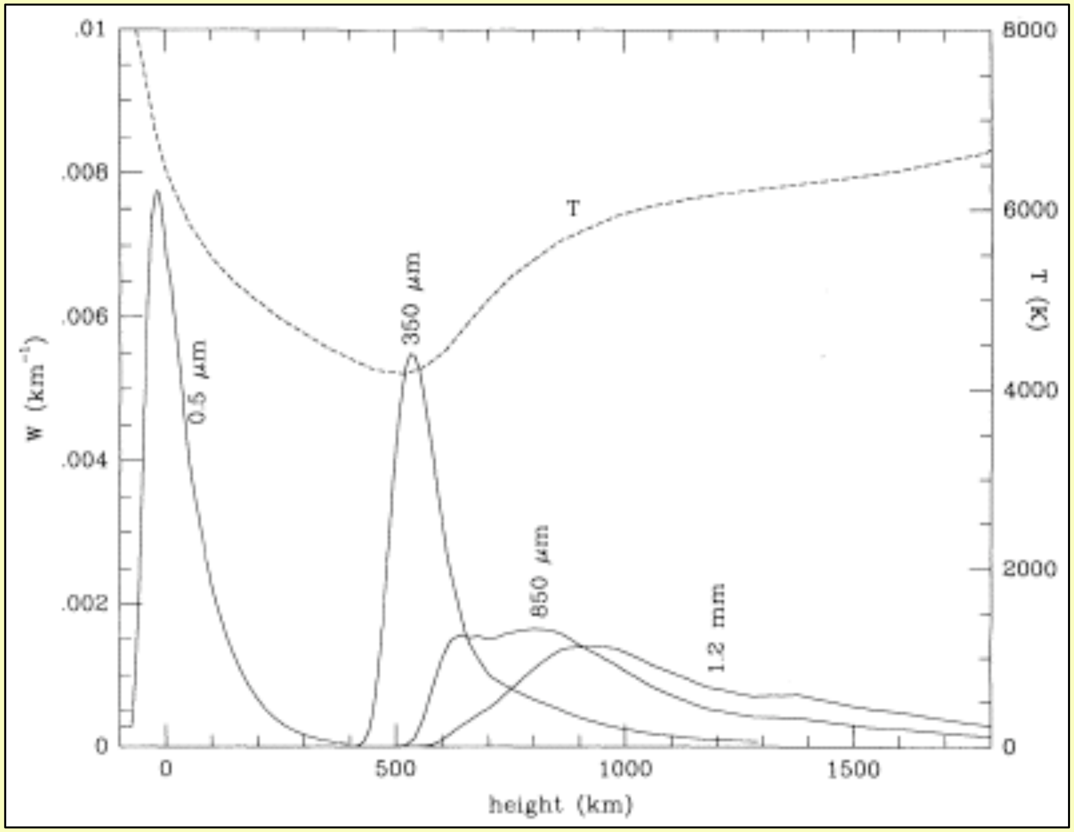
VAL-C Model Contribution Functions



Lindsey et al. 1995

Continuum pros and cons

- Opacity* generally grows with wavelength and with frequency relative to 1.56μ, so both IR and UV let us see higher up in the solar atmosphere
- The IR/FIR/submm regions have especially simple physics (free-free opacity dominates)
- Flare effects in the deeper atmosphere (if present) relate to strong perturbations
- Towards the IR, angular resolution decreases according to λ/D
- In the UV/EUV the continuum opacity depends metals and there is complicated RT

*Recall Kirchoff's law, $\varepsilon_\nu = \kappa_\nu B_\nu$?

The chromosphere as seen by BIMA at 3.5 mm

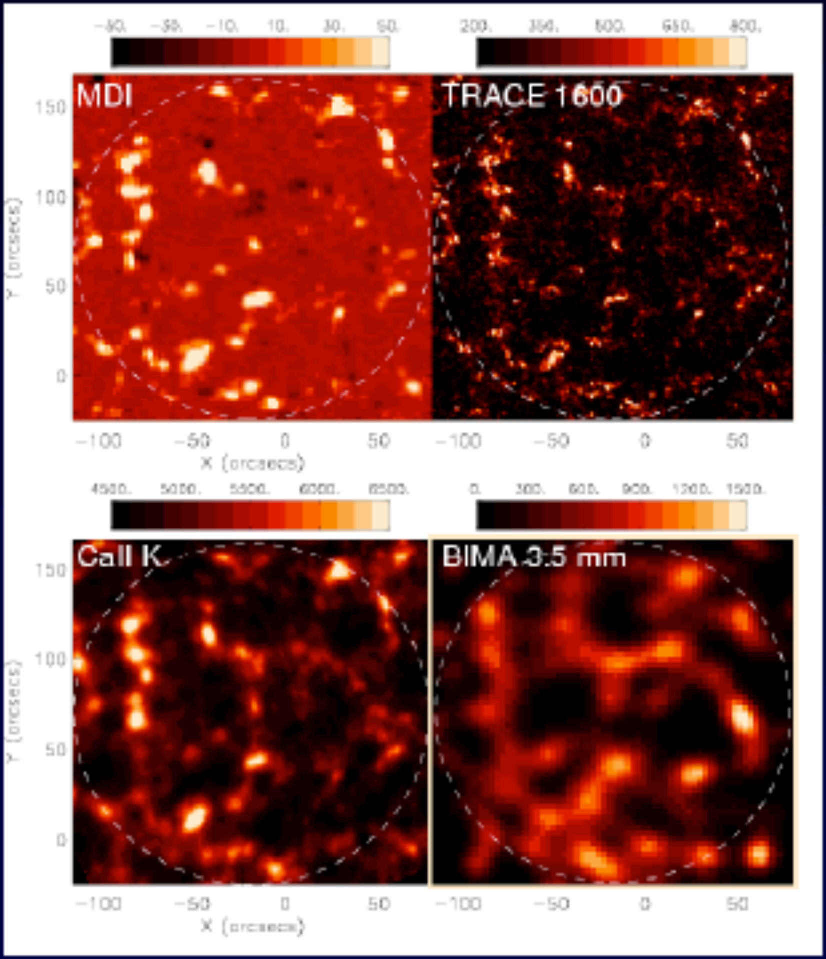
Fine structure at 3.5 mm

- size ~10" (<u>unresolved</u>)
- contrast ~30% of QS brightness

Brightness oscillations

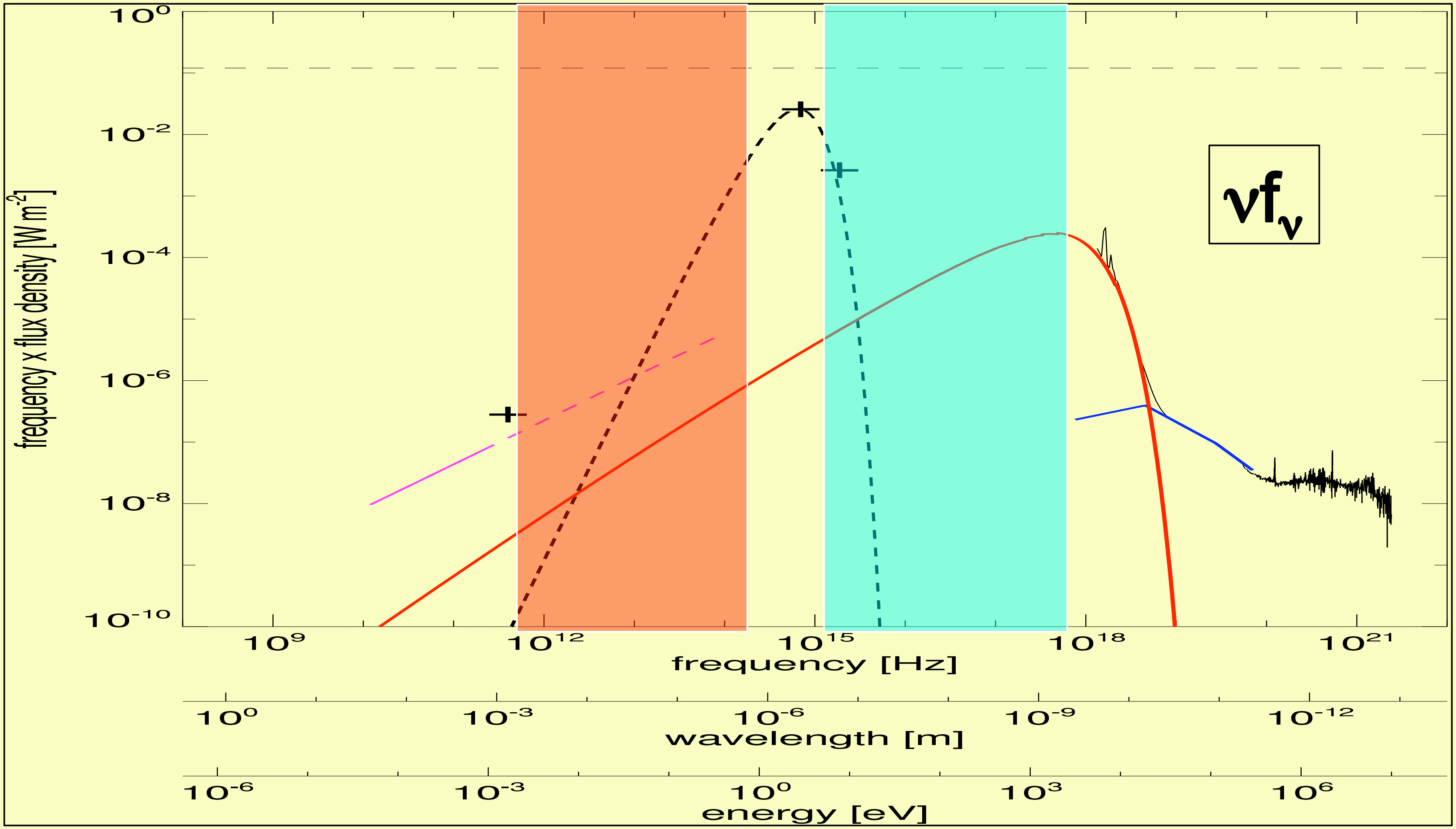
in 30 min observational runs:

- periods: 120-700 s (1.5-8 mHz)
- RMS amplitudes: ≤ 150 K
- P(NW) > P(IN)
- IN : 3-min component
- No. of wave packets: 1-3
- No. of wave periods: 1-3

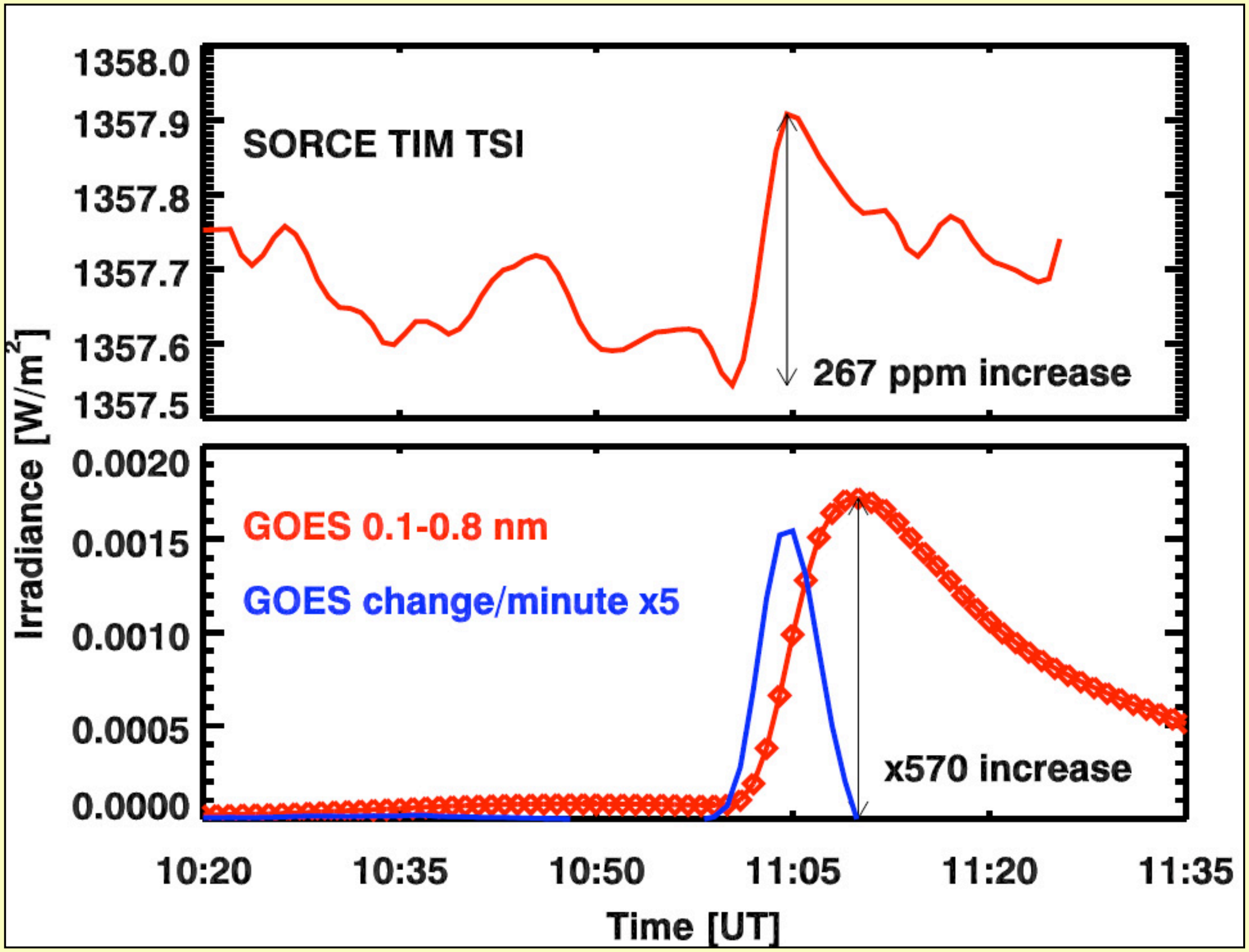


Loukitcheva et al 2008

Unknown Continuum Regions

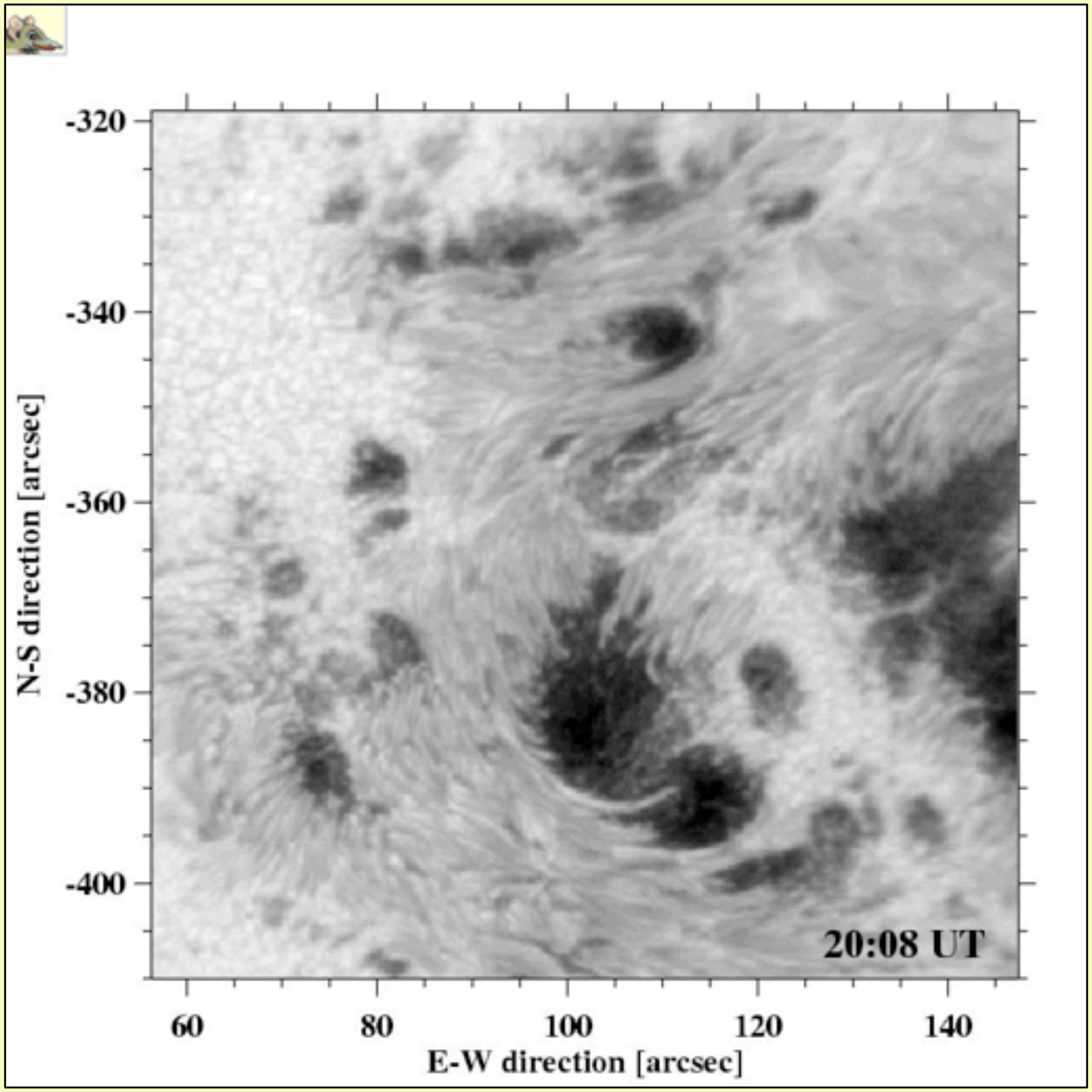


First bolometric observation of a solar flare



Woods et al. 2004

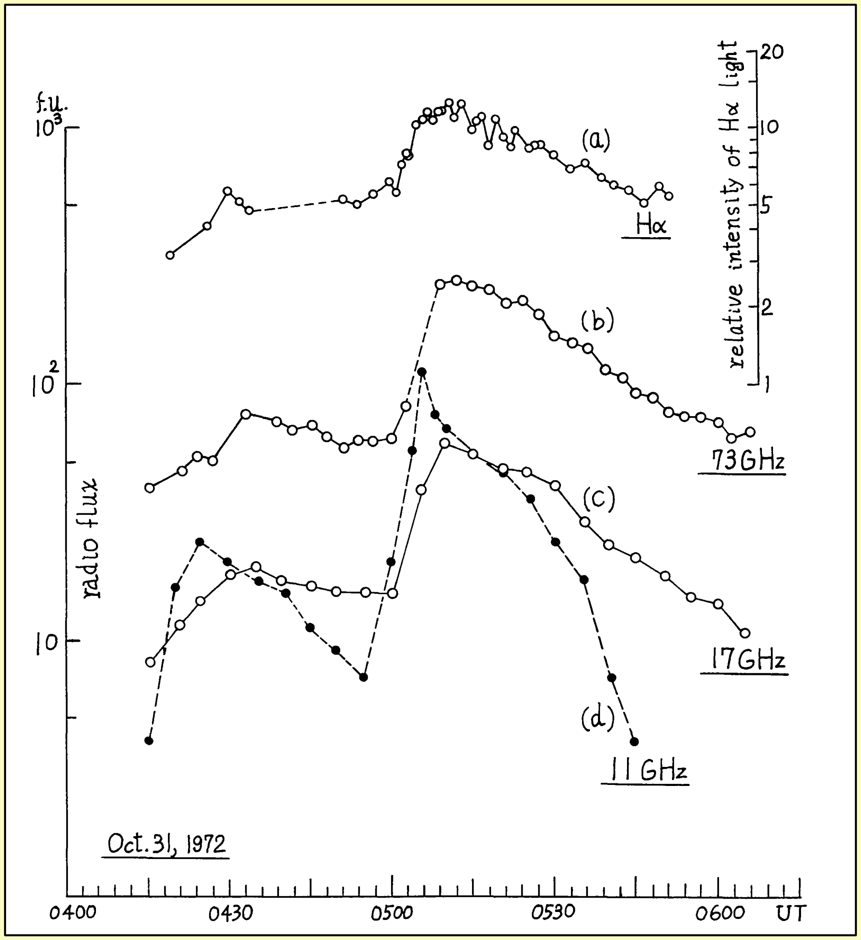
Xu et al. observations at "opacity minimum"



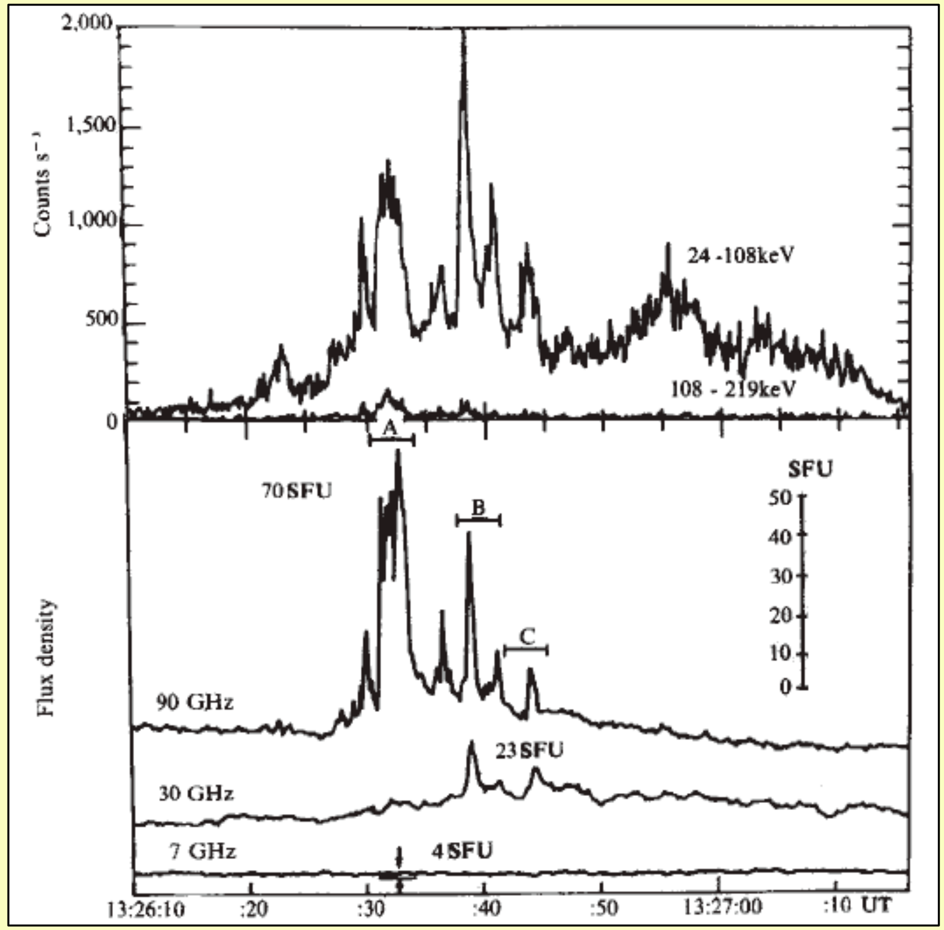
Overview of flare microwaves

- The electron Larmor frequency at 1 kG is 2.8 GHz
- Processes include free-free (bremsstrahlung) and gyrosynchrotron mechanisms
- “Mildly relativistic” electrons, ~1 MeV, are numerous enough to produce synchrotron emission in the impulsive phase of a flare
- These electrons appear to be an extension of the HXR-emitting electrons at lower energies
- Usually gyrosynchrotron spectra decrease with frequency, f ~ ν^{α}, α negative, above about 10 GHz

Historical mm-wave Flares

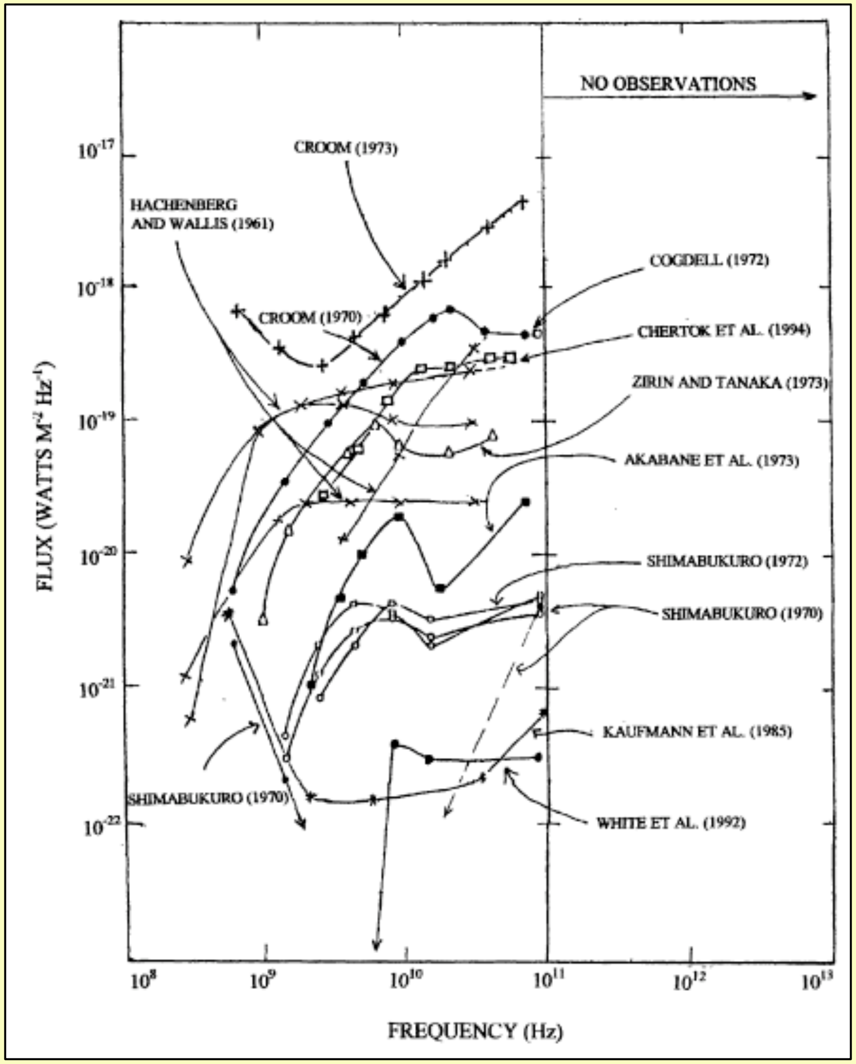


Akabane et al. 1973



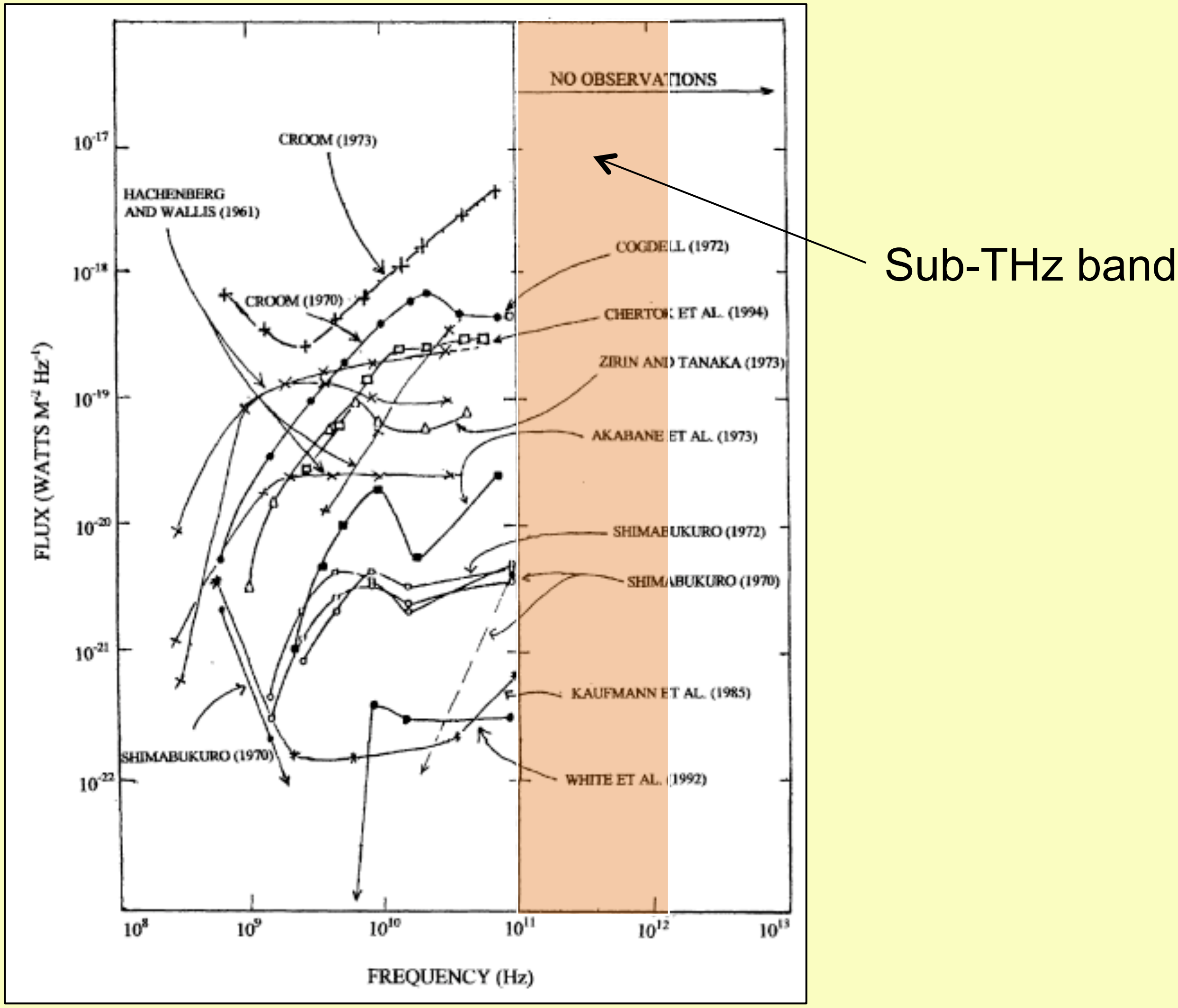
Kaufmann et al. 1985

Ancient mm-wave history



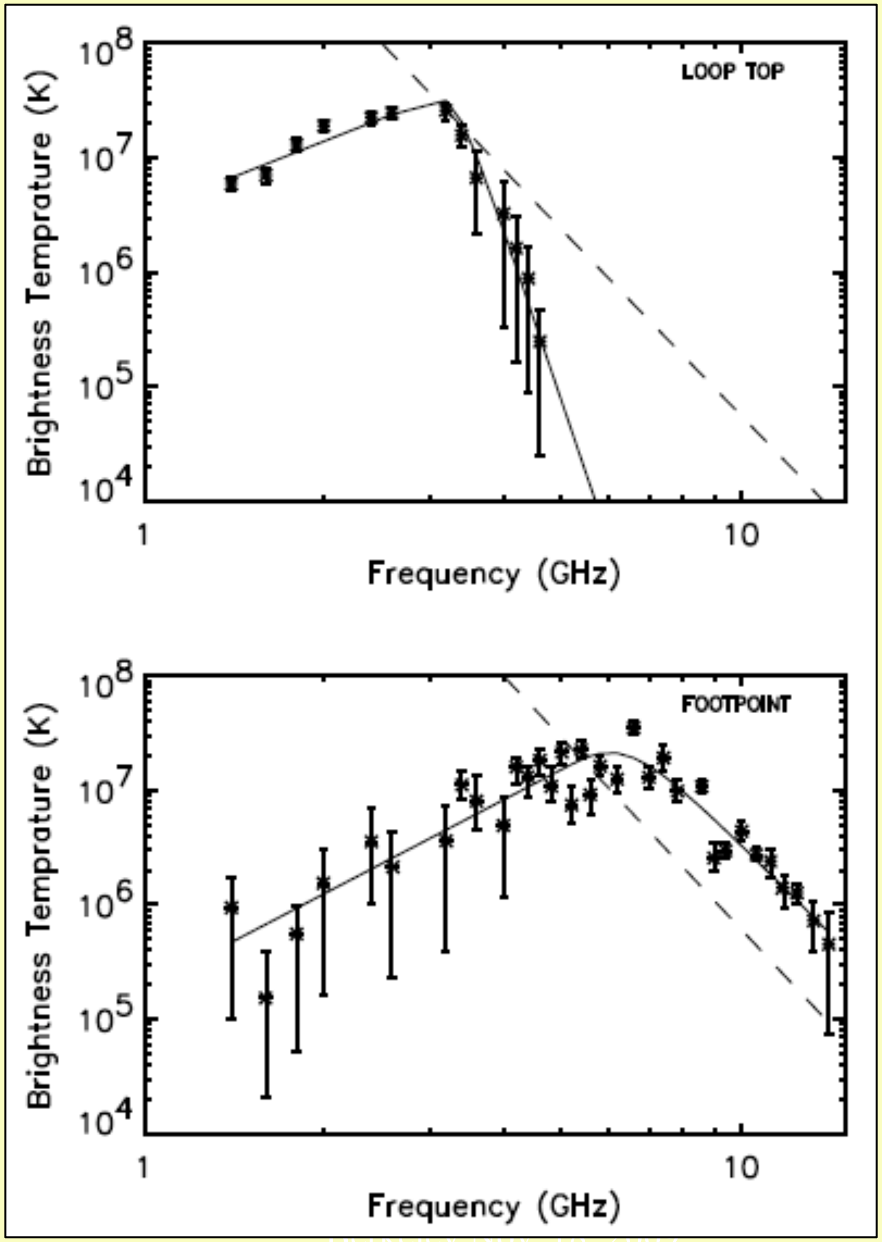
Kaufmann et al. 1996

Ancient mm-wave history



Kaufmann et al. 1996

A more typical event



Bastian et al. 1998

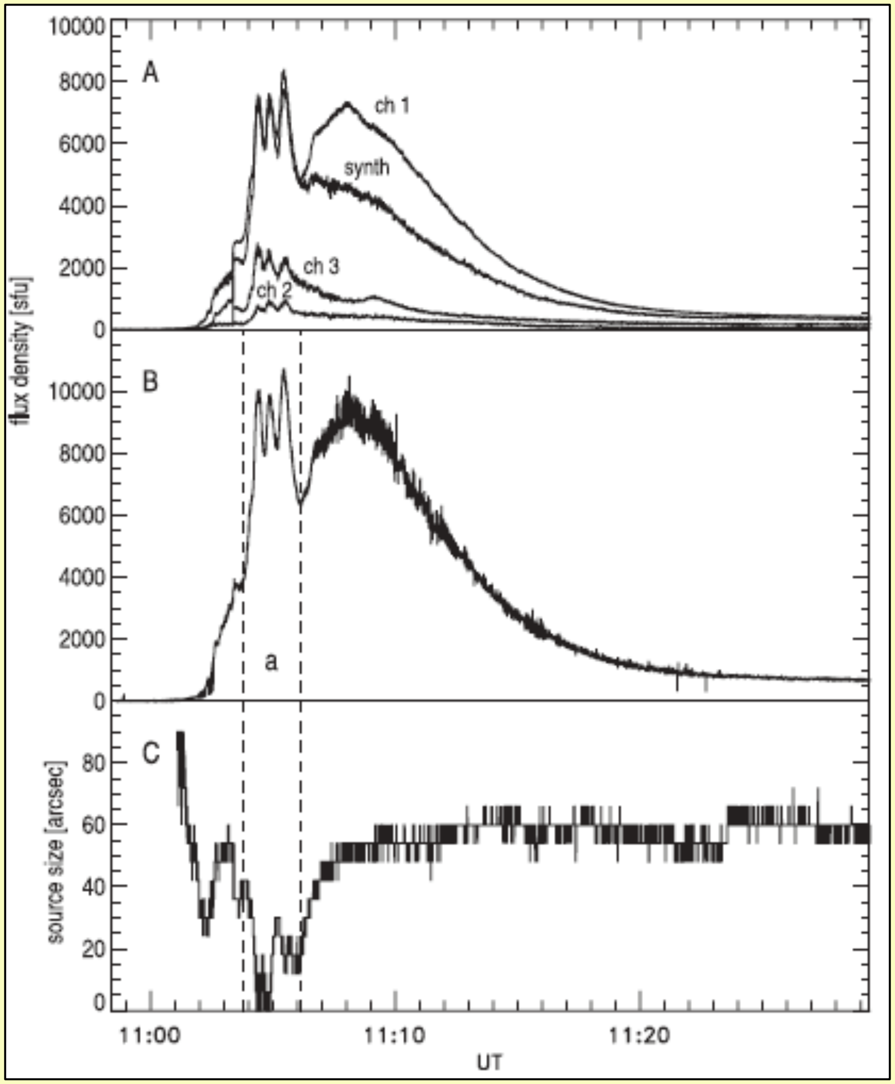
The Super-mm (sub-THz) Event Catalog, 2009

Table 1: Flare events with positive slope above 200 GHz

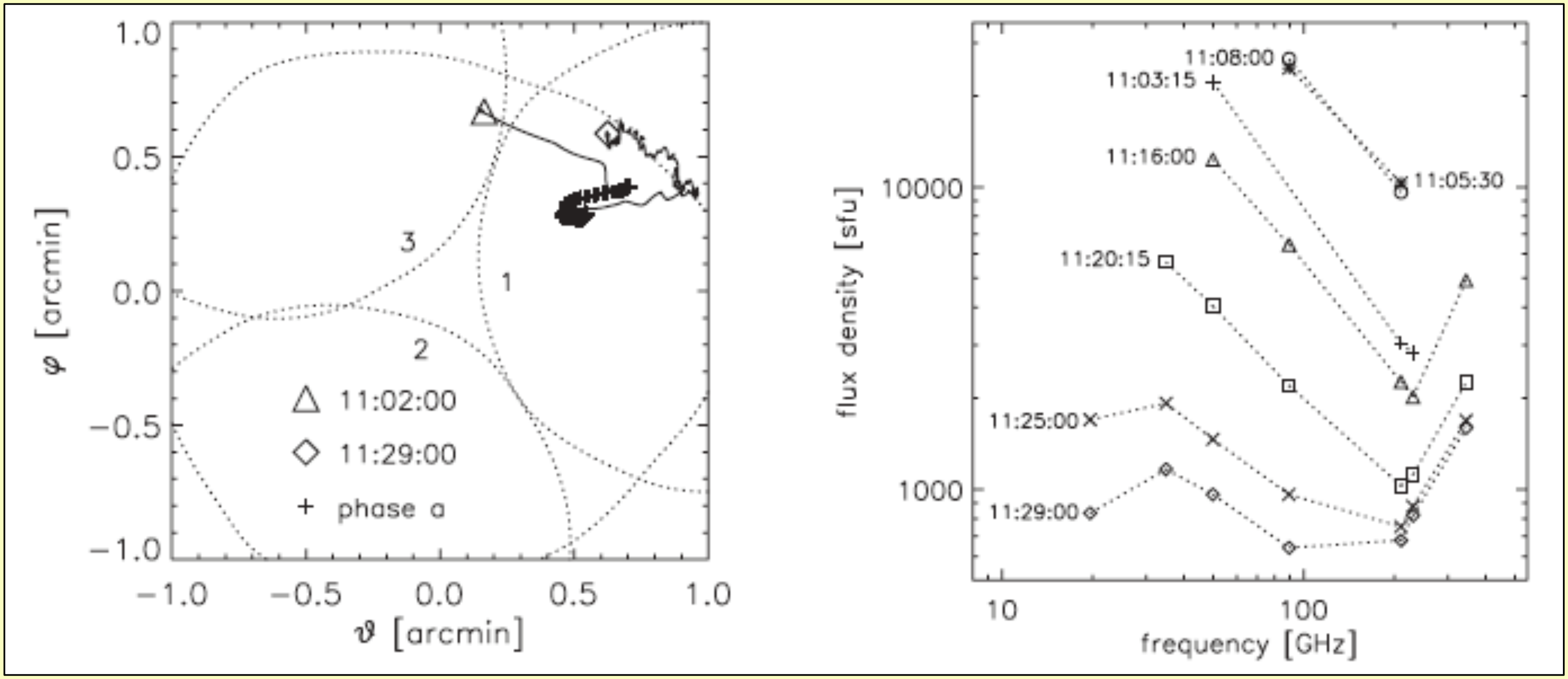
Date	GOES	Helio	Reference	P, I, G[a]	Comments
22-Mar-00	X1.1	N14W57	Trottet et al. (2002)	G?	15.4, 212
06-Apr-01	X5.6	S21E31	Kaufmann et al. (2002)	G?	OVRO, 212
12-Apr-01	X2.0	S22W31	Lüthi et al. (2004a)	I?, G	Very long duration
20-Dec-02	M6.8	S25W34	Cristiani et al. (2008)	I?	Marginal; GOES odd
28-Oct-03	X17	S16E08	Lüthi et al. (2004b)	P, I, G	Size estimates
					Very long duration
02-Nov-03	X8.3	S14W56	Silva et al. (2007)	I, G	Difficult photometry
04-Nov-03	>X28	S19W83	Kaufmann et al. (2004)	I, G	G off the limb?
06-Dec-06	X6.5	S06E63	Kaufmann et al. (2009)	P, I, G?	

[a]Pre-impulsive, Impulsive, Gradual

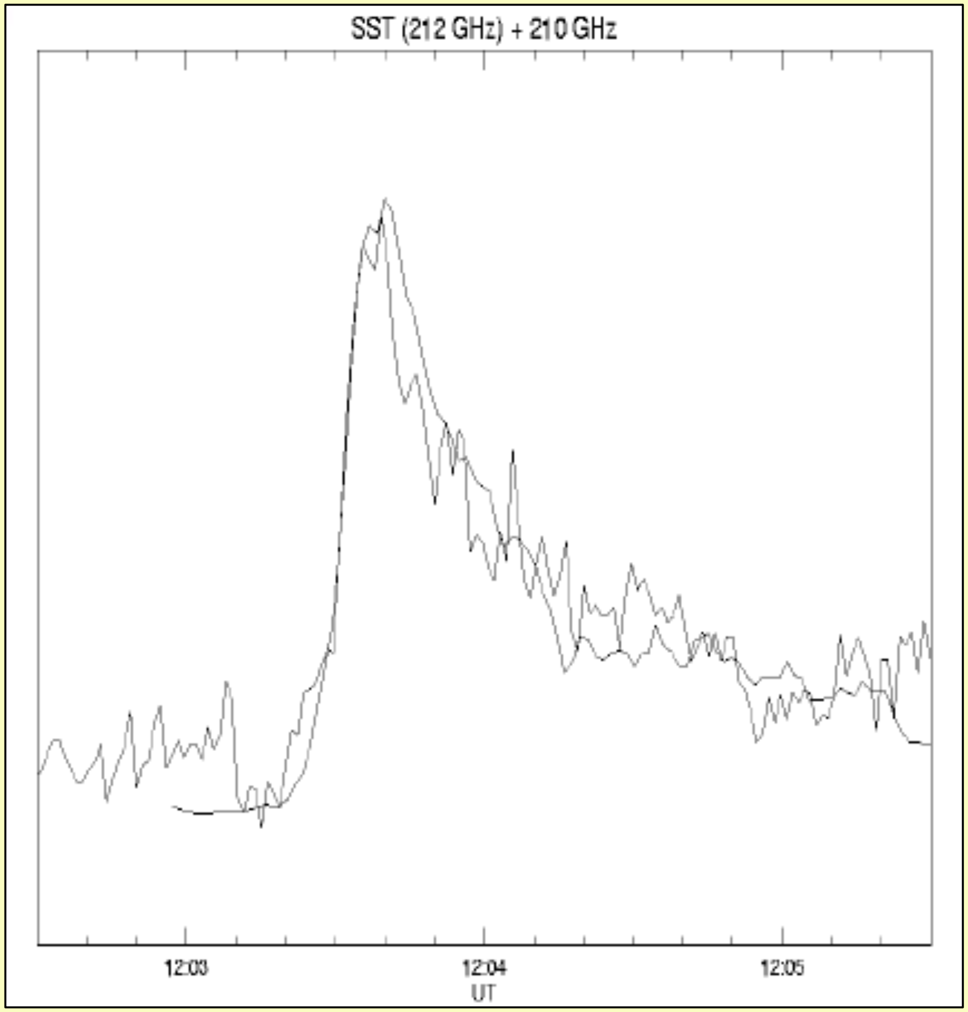
Source Sizes (Lüthi), 28-Oct-03



Positions and Spectra



SST/BEMRAK Comparison



Interpretation

- Gyrosynchrotron electrons: it would have to be different populations of electrons at radically high fields and particle energies
- Gyrosynchrotron positrons: ruled out by 511 keV?
- Thermal: it seems impossible to explain the impulsive sources this way, but maybe OK for gradual ones
- Exotic: there are several ideas capable of positive slopes in principle:

  - Coherent emission(s)

  - Cherenkov radiation

  - other

Emission Mechanisms

Mechanism	PRO	CON
free-free	known mechanism rising spectrum	Not viable for compact sources Fast time variations (?)
Electron synchrotron	known mechanism rising spectrum (razin or absorption) fast time variations	'extreme' parameters needed to reproduce observations
Positron synchrotron	time and space coincidence with γ-ray observations fast time variations	not enough positrons (as derived from gamma-ray observations)
Vavilov-Cherenkov	rising spectrum large fluxes rapid variations	dielectric properties of chromosphere not known (i.e. refractive index could be smaller)
Bunching	association with GHz emission	THz emission attributed to electron synchrotron (see above) setup of bunching is unclear coronal microwave sources difficult to explain
Plasma emission	correlation with γ-rays low number of particles needed	needs high densities and collisions should therefore be important not otherwise observed above 8 GHz
Diffusive radiation	Rising spectrum	Origin of high levels of long-wavelength Langmuir waves
Thermal Gyrosynchrotron	Rising spectrum	Extreme parameters Associated thermal hard X-ray emission not observed
Synchrotron Maser	Low number of particles needed	
Transition radiation	Rising spectrum	
Inverse Compton	association with GHz emission	not enough primary photons

Conclusions

- The ISSI team's goal is to take an impartial look at the body of "sub-THz" or "super-mm" observations
- Yes, the observations are credible, at least regards spectral distribution
- No, we do not know how to explain them yet
- ALMA will be good but needs scientific interest and participation
- Dedicated observing programs, such as that at El Leoncito, will also exist – will solar activity?