Solar observations with LLAMA

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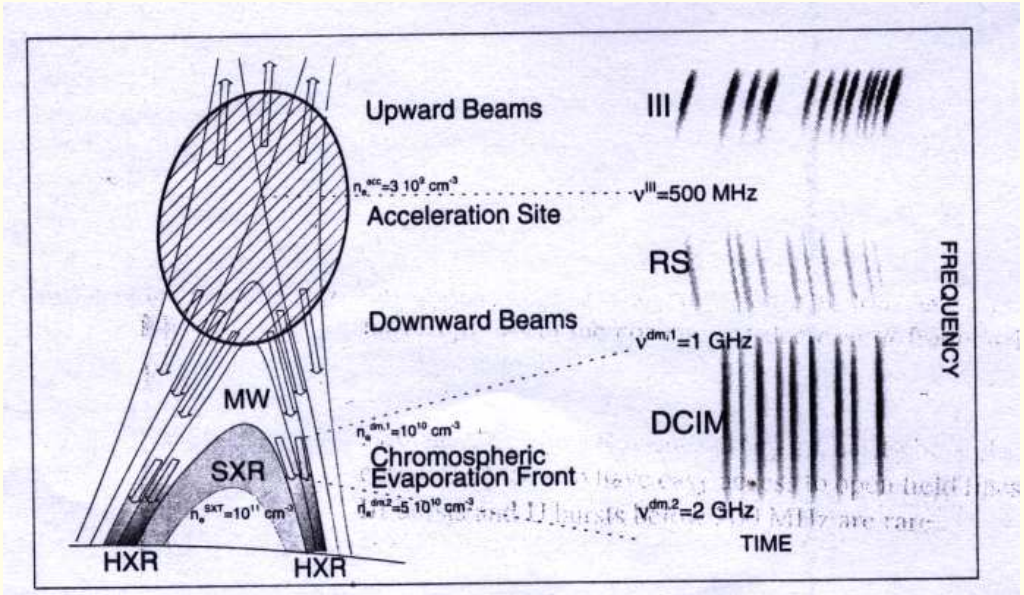
Science with LLAMA
September 5 – 9, 2022, Salta, Argentina

Solar flares (radio bursts)

- Energies 10^{29} – 10^{32} ergs
- Typical times 10^{2} – 10^{3} sec
- Produced by magnetic recconection

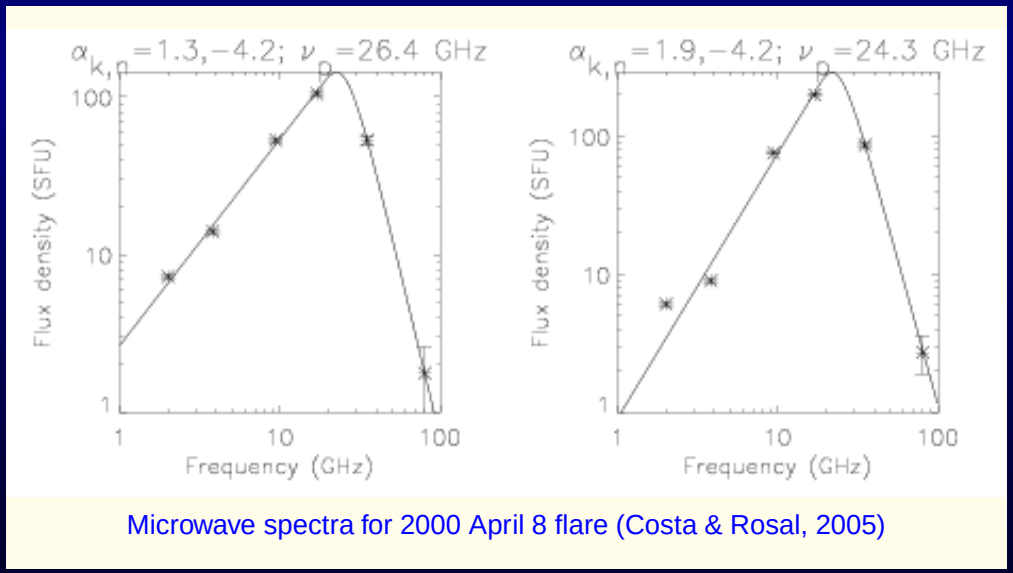
- Plasma heating
- Particle acceleration
- MHD waves
- Radiation



Sketch of a solar flare (Aschwanden & Benz, 1997)

Microwave observations

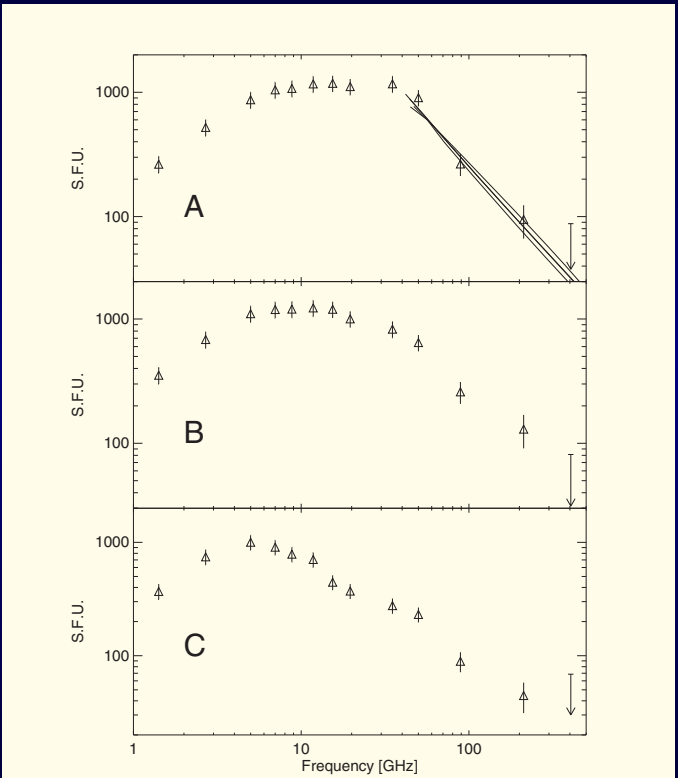
- Owens Valley Solar Array (OVSA, 1 - 18 GHz)
- Radio Solar Telescope Network (RSTN, 245 MHz - 15.4 GHz)
- Nobeyama Radio Heliograph (NoRH, 17 and 34 GHz)
- Nobeyama Radio Polarimeter (NoRP, 1 - 80 GHz)
- Pierre Kaufmann Radio Observatory (AKA Itapetinga Radio Observatory, 18 - 26 GHz and 40 - 50 GHz)



Microwave spectra for 2000 April 8 flare (Costa & Rosal, 2005)

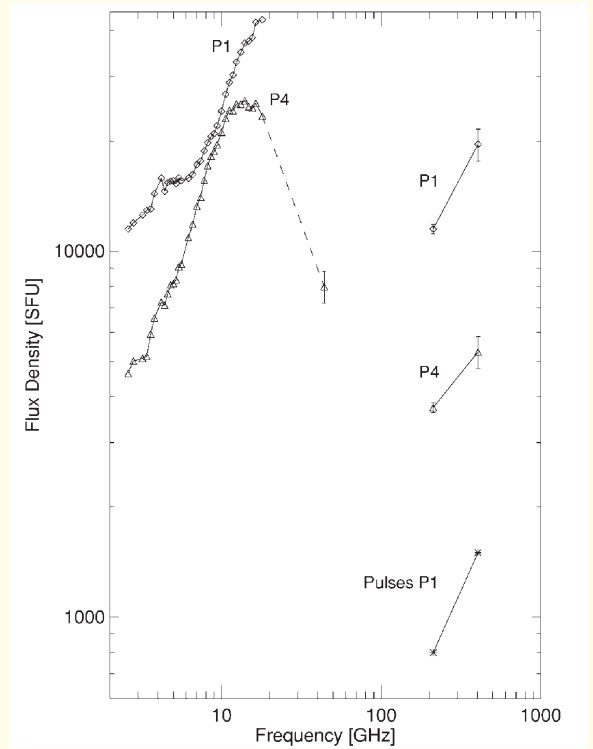
Submillimeter observations

- Solar Submillimeter-wave Telescope (SST, 212 and 405 GHz)
- Kölner Observatorium für Submillimeter und Millimeter Astronomie (KOSMA, 210 and 345 GHz)



A "normal event" observed at sub-mm wavelenghts on August 30, 2002 (Giménez de Castro et al., 2009)

Normal event



The first detected THz event, on November 4, 2003 (Kaufmann et al., 2004)

THz event

Sub-mm events exhibiting the THz component

- Free – free
- Synchrotron (electrons)
- Synchrotron (positrons)
- Synchrotron (thermal)
- Cherenkov
- Microbunching
- Plasma emission
- Inverse Compton
- Diffusive radiation
- Synchrotron maser

. List of flares with a rising spectrum of sub-THz emission.

Solar flare (GOES class)	Sub-THz (UT)	δ	F. density (sfu)
SOL2000-03-22T18:48 (X1.1)[a]	18:50:00	$1.27^{+0.63}_{-0.63}$	500
SOL2001-04-12T10:28 (X2.0)[b]	10:17:54	$1.09^{+0.96}_{-1.07}$	810†
SOL2003-10-27T12:43 (M6.7)[c]	12:32:30	$1.68^{+0.48}_{-0.49}$	86†
SOL2003-10-28T11:10 (X17)[d]	11:16:12	$2.0^{+0.8}_{-0.53}$	4500†
SOL2003-11-02T17:25 (X8.3)[e]	17:19:30	$3.41^{+2.92}_{-1.79}$	50 000
SOL2003-11-04T19:50 (X28)[f]	19:44:00	$0.71^{+0.23}_{-0.24}$	18 000
SOL2006-12-06T18:47 (X6.5)[g]	18:43:51	$0.98^{+0.68}_{-0.93}$	6800
SOL2012-10-22T18:51 (M5.0)[h]	18:48:30	$1.42^{+0.48}_{-0.49}$	50
SOL2012-07-04T09:55 (M5.3)[i‡]	09:55:30	$1.29^{+0.6}_{-0.63}$	39‡
SOL2012-07-05T11:44 (M6.1)[j‡]	11:44:24	$1.33^{+0.6}_{-0.63}$	26‡
SOL2013-02-17T15:50 (M1.9)[h]	15:46:25	$1.42^{+0.28}_{-0.28}$	200
SOL2014-10-27T14:47 (X2.0)[h]	14:22:50	$1.07^{+0.31}_{-0.31}$	60
SOL2014-11-05T19:44 (M2.9)[h]	19:53:40	$0.63^{+0.4}_{-0.38}$	30
SOL2014-11-07T17:26 (X1.6)[h]	17:25:30	$0.52^{+0.29}_{-0.29}$	70

Kontar et al., 2018.

Sub-THz radio data are from the following papers: (a) Kaufmann et al., 2001; Trottet et al., 2002; (b) Lüthi et al., 2004a; (c) Trottet et al., 2011; (d) Lüthi et al., 2004b; Trottet et al., 2008; (e) Silva et al., 2007; Kaufmann et al., 2009a; (f) Kaufmann et al., 2004 and 2009b, (g) Kaufmann et al., 2009b; (h) Fernandes et al., 2017; (i) Tsap et al., 2016; (j) Tsap et al., 2018.

Kaufmann & Raulin (2006), Kaufmann et al. (2009), Krucker et al. (2013), Kontar et al. (2018)

Future LLAMA Observations – Flares

Difficulties

- Lack of a multibeam system
- Small beam sizes at higher frequencies

Possible solutions

- Phase 1: Determination of the source location
  - Complimentary instrument (flare finder)
  - Fast scans
- Phase 2: Observations with on-the-fly mapping
  - OTF map of $2' \times 2'$ $\longrightarrow$ 12 sec
  - OTF map of $3' \times 3'$ $\longrightarrow$ 20 sec

Future LLAMA Observations – quiet Sun

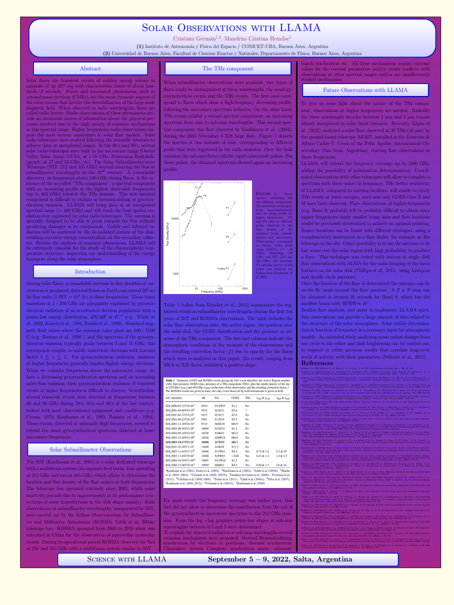
Daily mapping:

- Solar radius determination: $R(\nu)$
- Limb brightening intensity observation

Analysis:

- Input for atmospheric models
- Correlation with the level of activity (Selhorst et al., 2011)

Thanks a lot!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