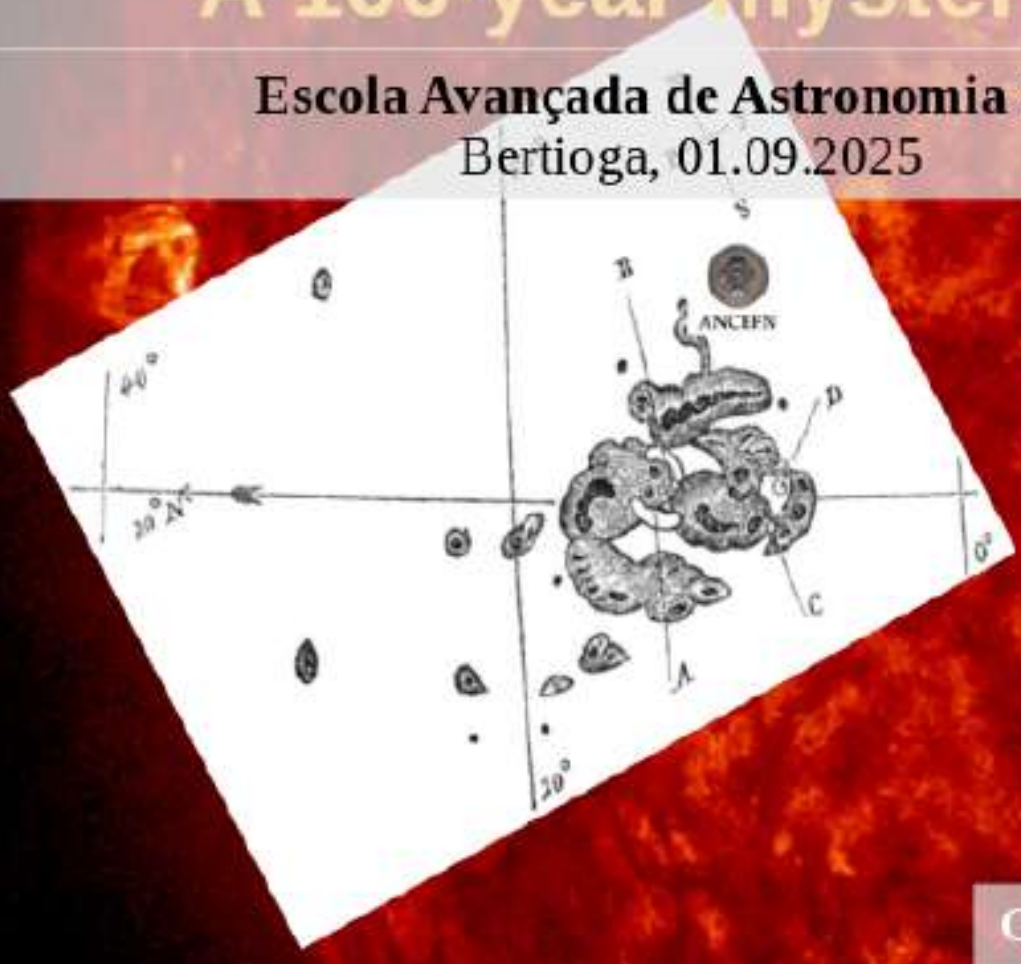
Cromospheric Flares

A 166-year mystery

Escola Avançada de Astronomia 2025

Bertioga, 01.09.2025

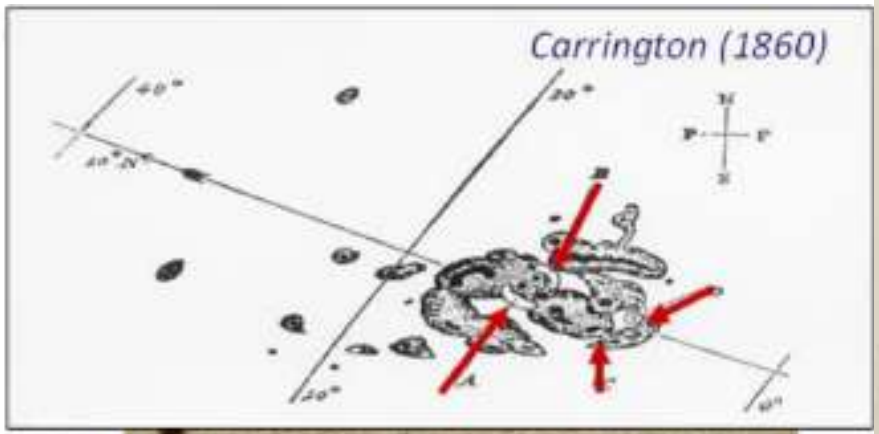


Guillermo Giménez de Castro

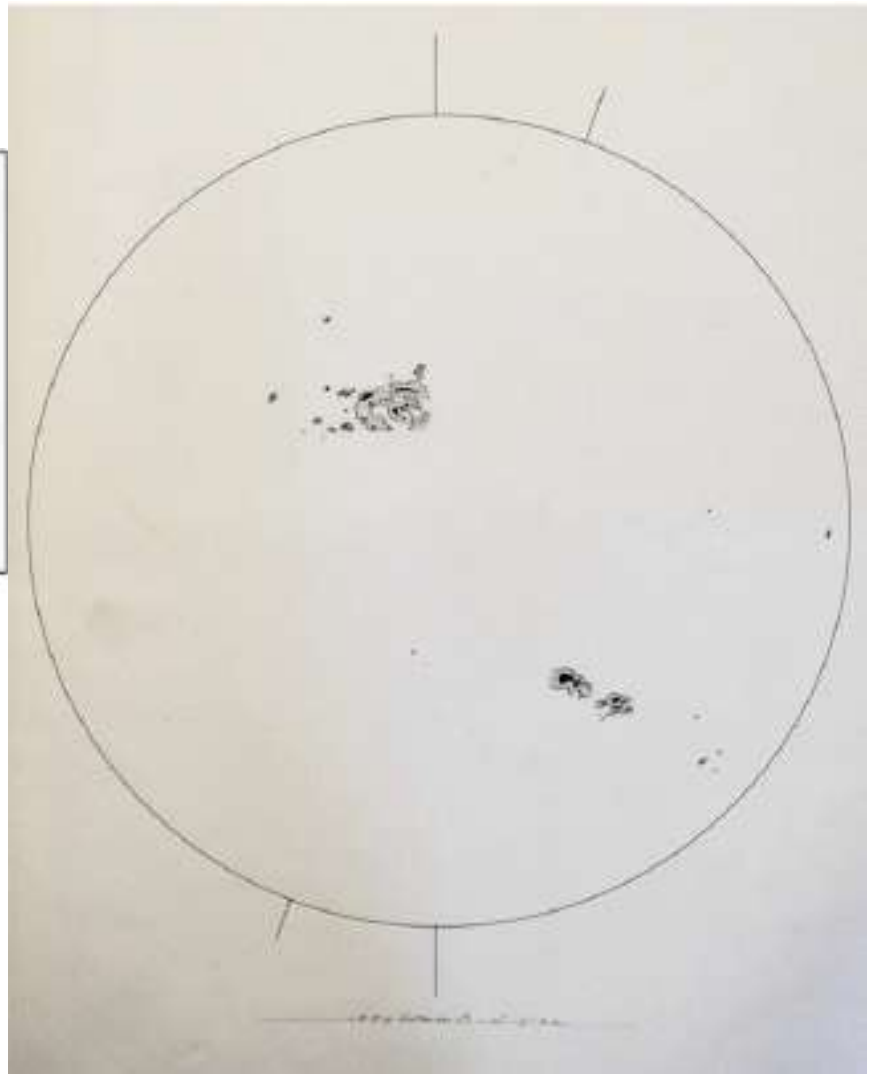
September 1st, 1859

Richard Carrington

(A)



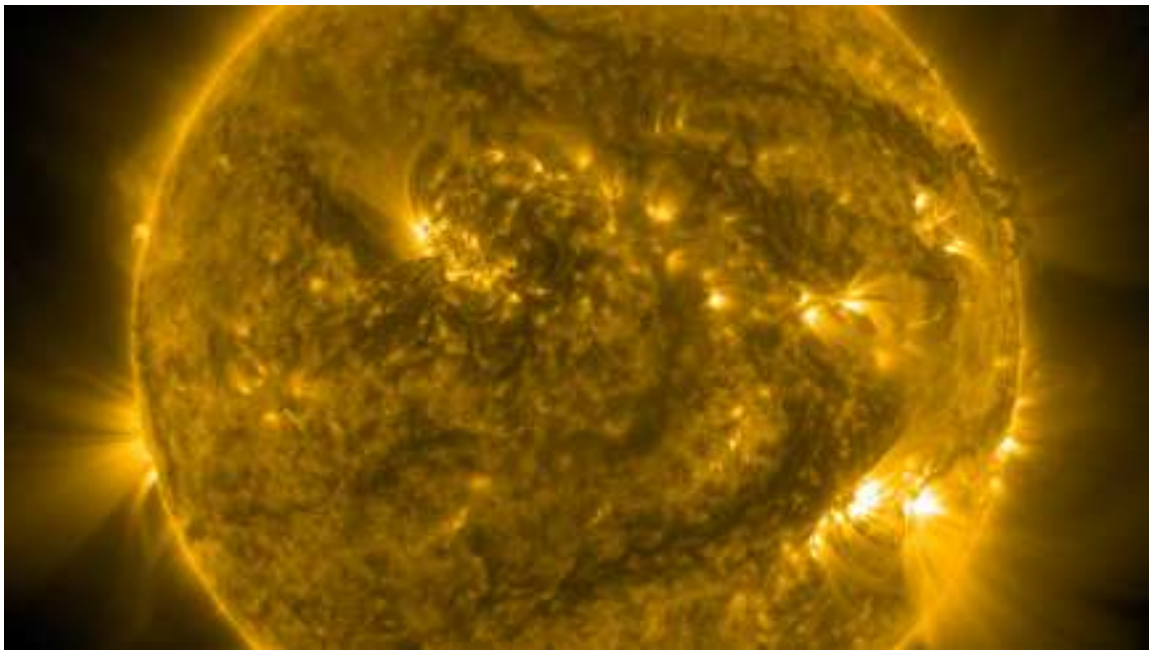
(B)



Hα flares

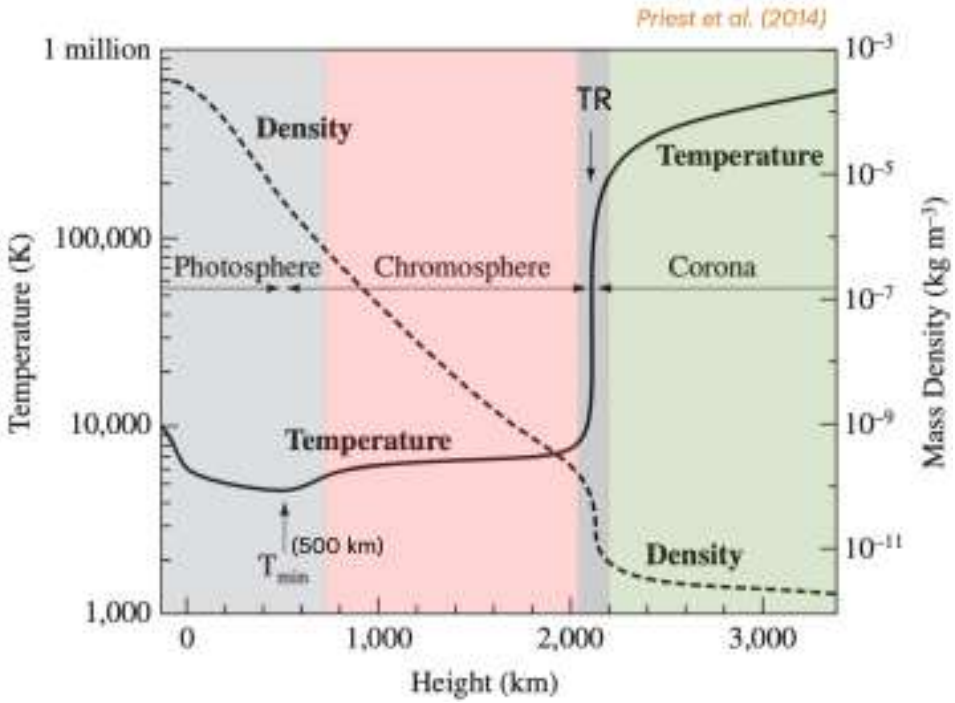
Flare observed in Hα at *Big Bear Solar Observatory*.

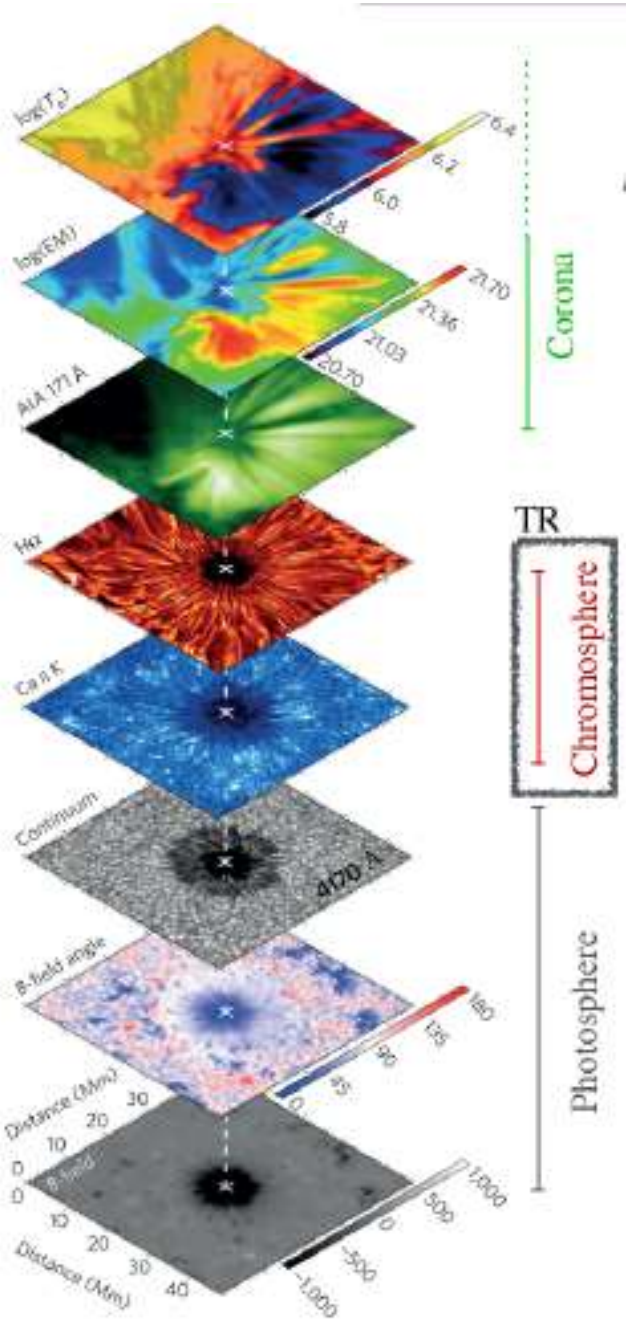
UV Coronal flares



Flares observed in UV with AIA on board of SDO.

Solar Atmosphere





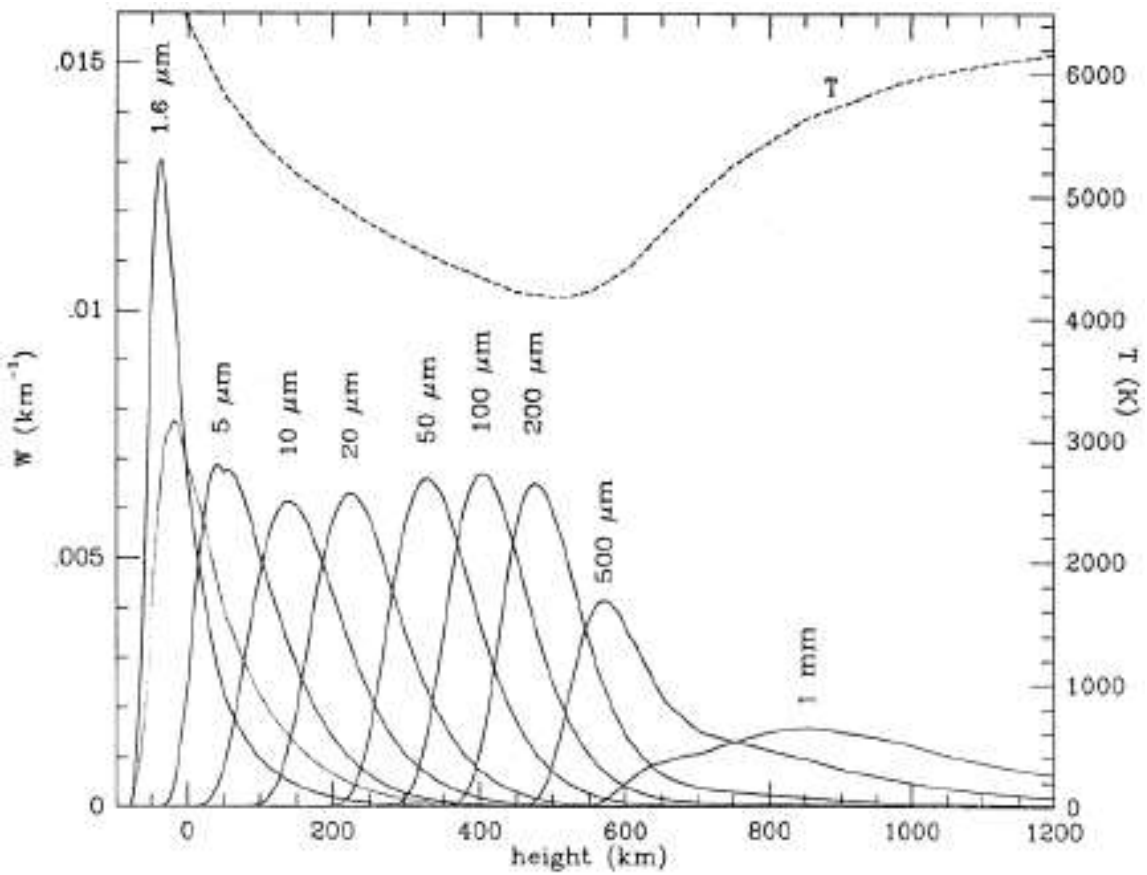
Beyond radio: the Infrared

The Radio+

- Range: $\sim$ 1 mm (300 GHz) $\geq \lambda \geq \sim$ 1 μm (300 THz)
- 3 orders of magnitude.
- Technology emerged recently($<$ 40 years).
- Need for high altitude observatories. ($\geq$ 2.5 km).
- Same emission mechanism.
- Sun Emission Site: Photosphere to low Chromosphere.

Jefferies (1994)

The Quiet Sun IR continuum

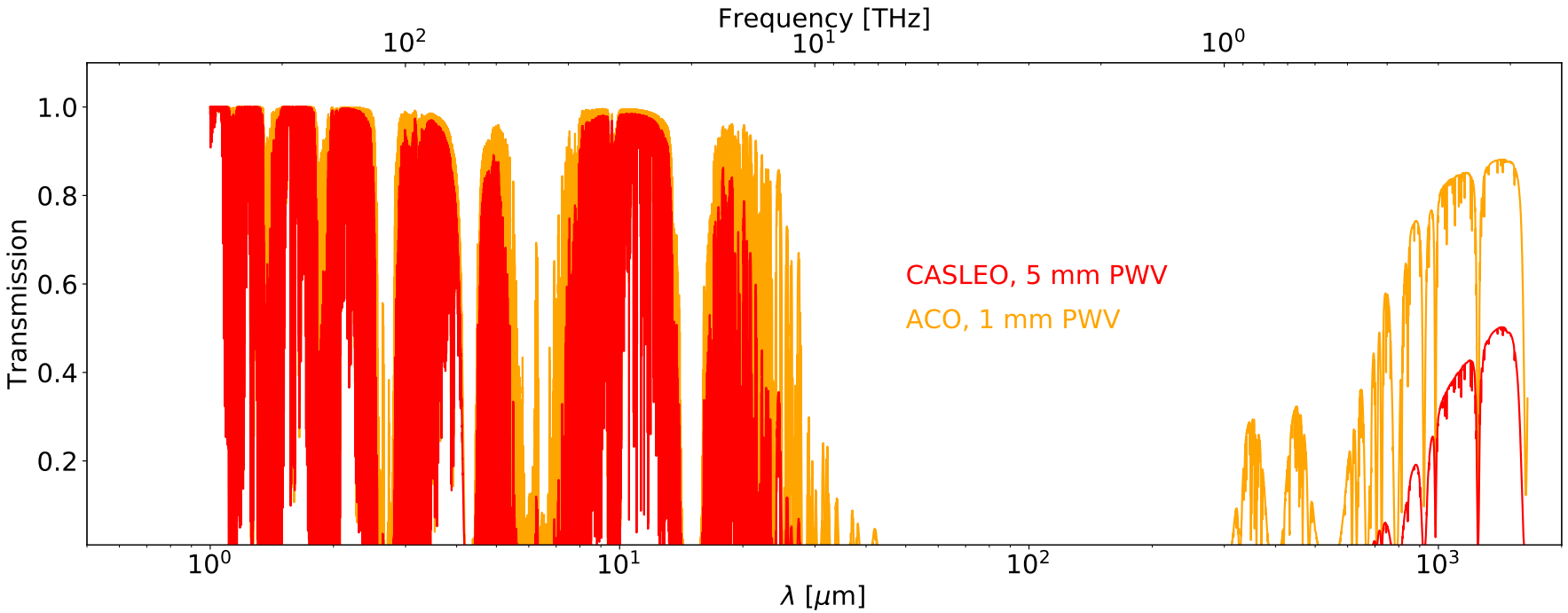


Jefferies (1994)

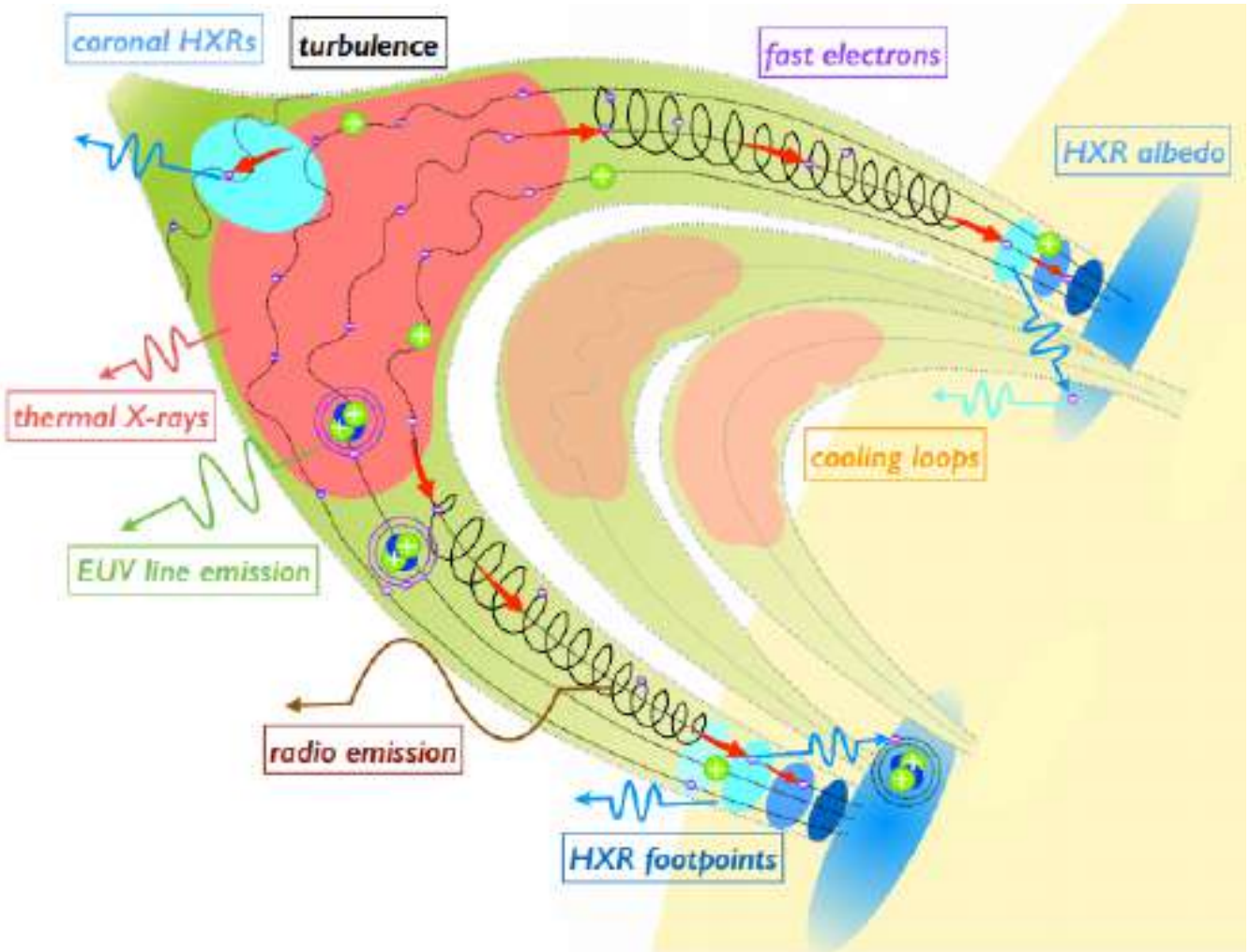
- Thermal Bremsstrahlung: *free–free* e^-–neutral (H^-), e^-–ion.
- Black Body Source Function.
- The Black Body function is approximated by Rayleigh-Jeans: $F \approx 2k_B T\nu^2/c^2$.
- Flux is proportional to temperature.

The Earth atmosphere in the IR

Atmospheric transparency to the zenith in function of the wavelength for Alto Chorillos (ACO, 4.8 km asl) with a PWV=1 mm (orange), and for CASLEO (2.5 km asl) and PWV=5 mm (red).



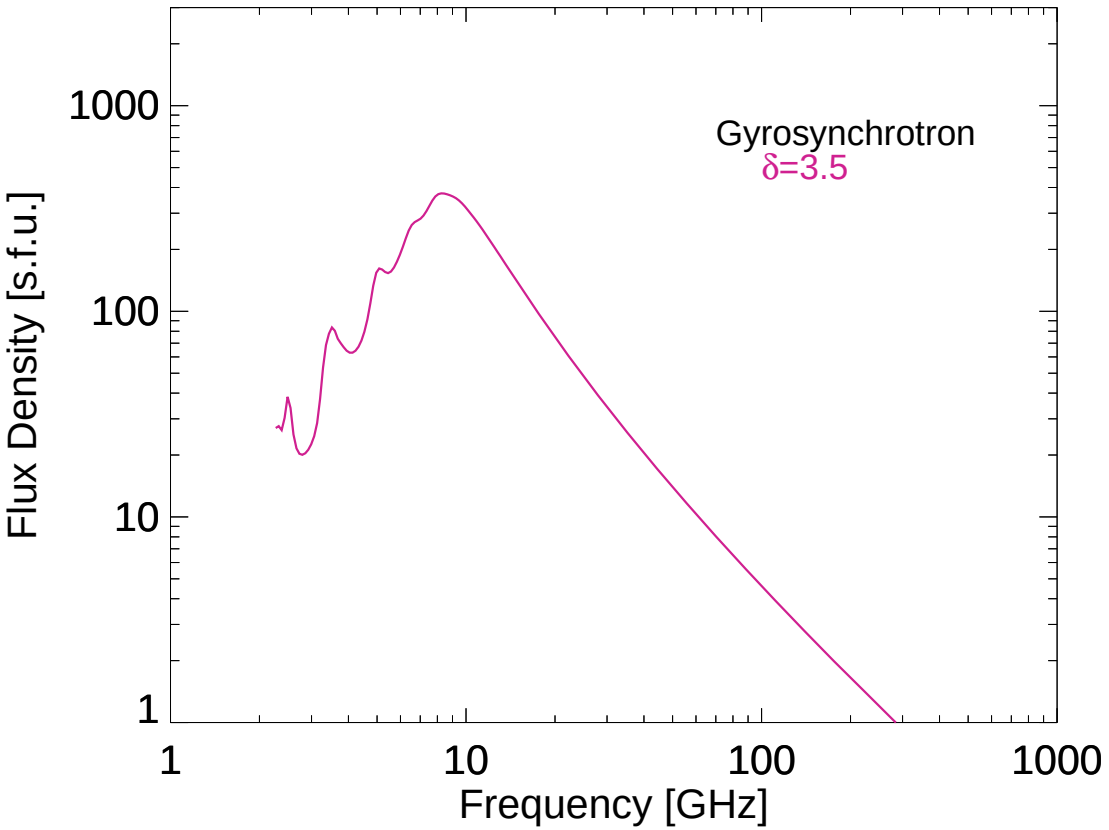
Flare Cartoon



Kontar et al., 2017

Flares in Radio+

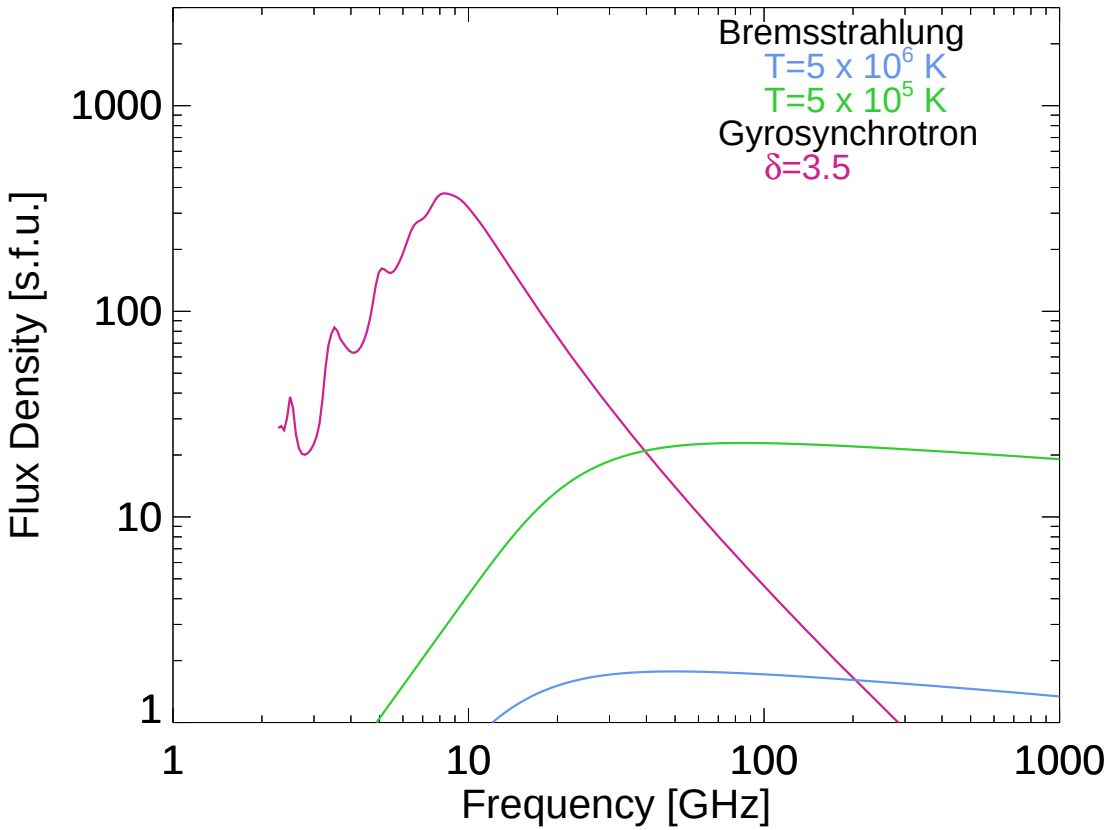
From microwaves to NIR



- Microwaves: $1 \leq \nu \leq 100$ *GHz*, $300 \leq \lambda \leq 3$ *mm*.
- *Gyrosynchrotron* from accelerated e^-.
  - $1 < \gamma_L < 3$.
  - $dN/dE \propto E^{-\delta}$
  - $N_{total} \sim 10^{3\cdots}$
  - $B \sim 100 - 1000$ G
  - Partially polarized.

Flares in Radio+

From microwaves to NIR

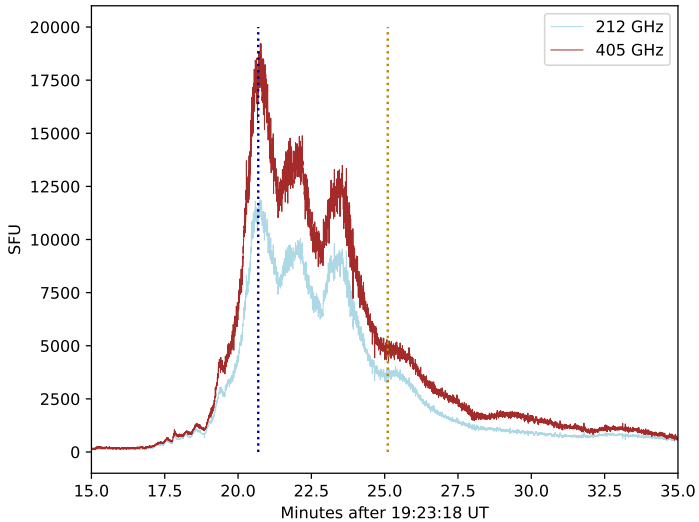


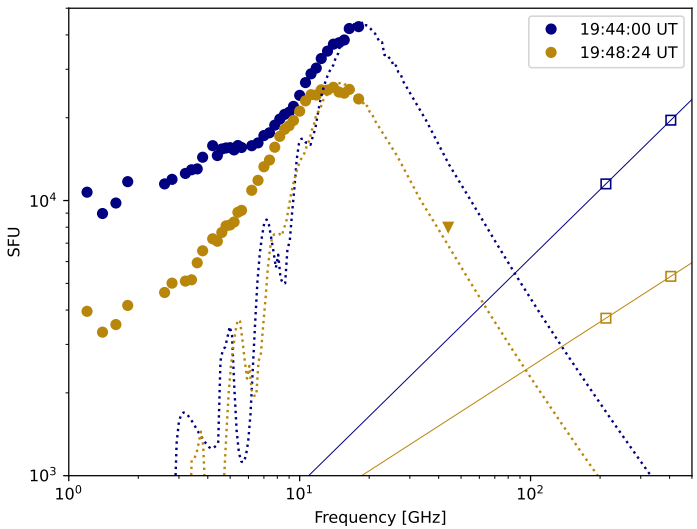
- Thermal Bremsstrahlung:
  - It depends on the plasma density and temperature.
  - Unpolarized.

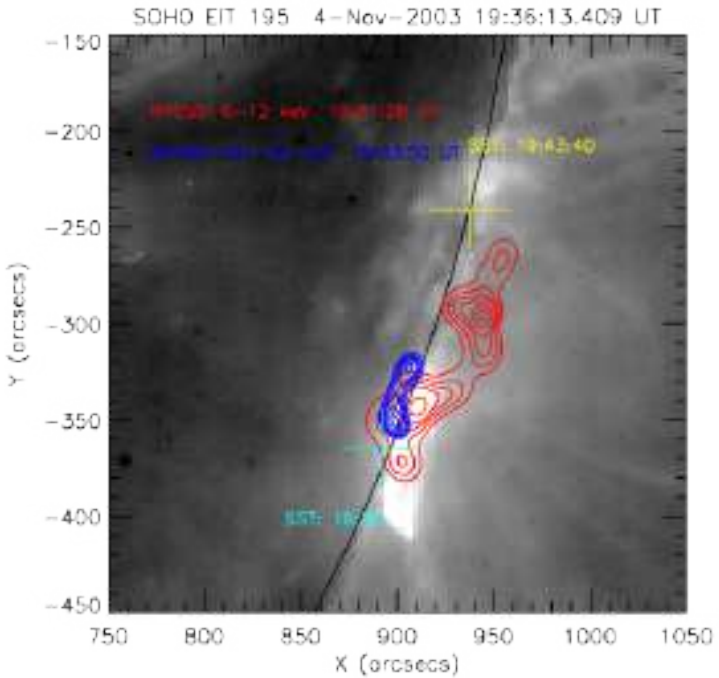
Observations

SOL2003-11-04

X43 THz event







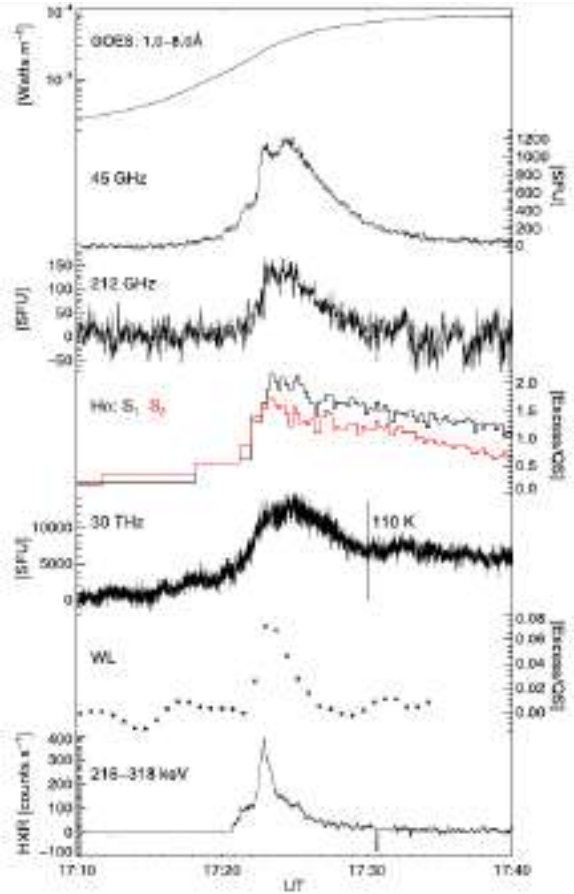
Kaufmann et al., 2004

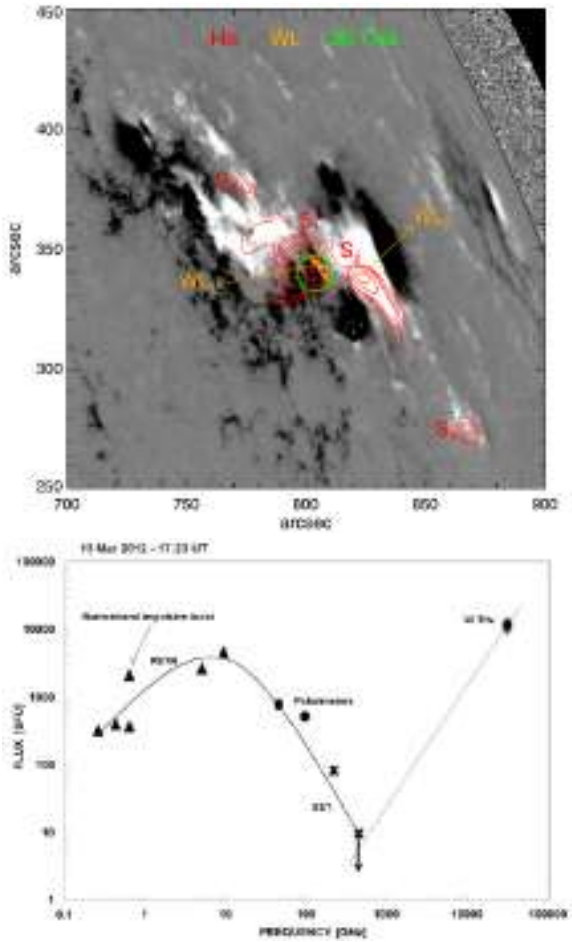
mid-IR continuum flares

SOL2012-03-13

Goes class M8

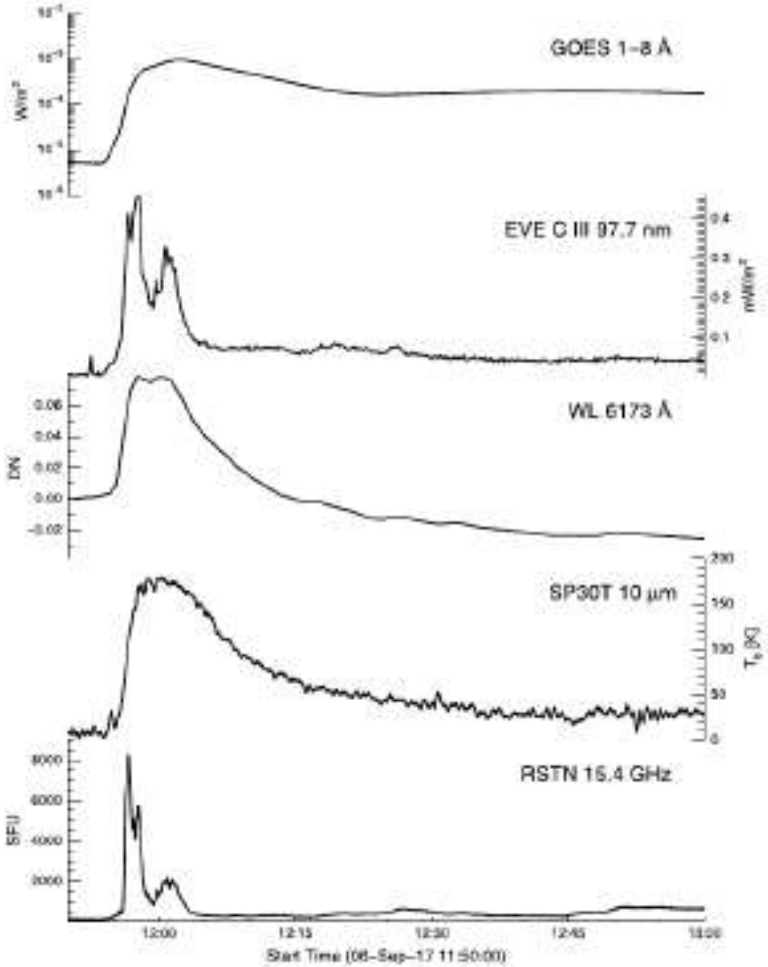
30 THz (10 μm), uncooled sensor, 13 arcsec spatial resolution.

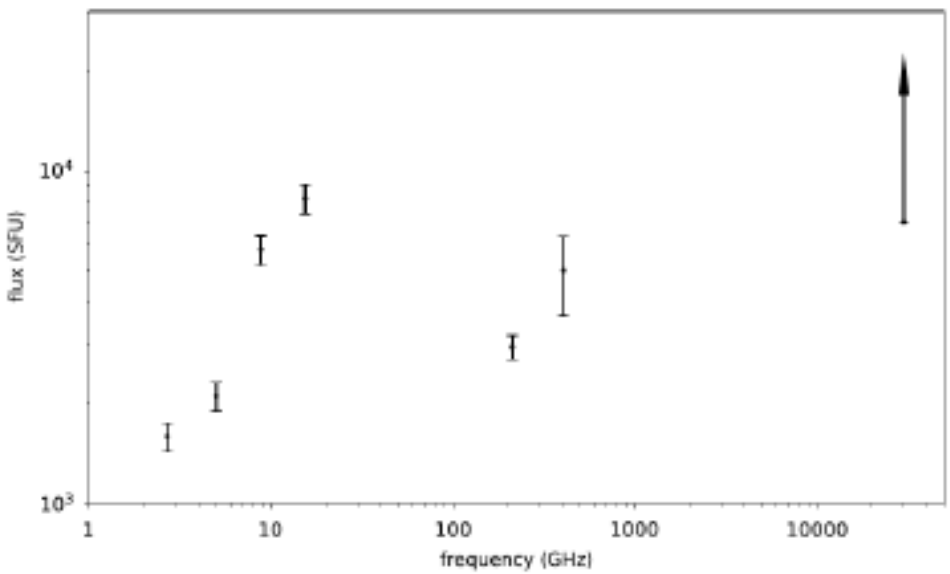




Kaufmann et al, 2013 & Trottet et al, 2015.

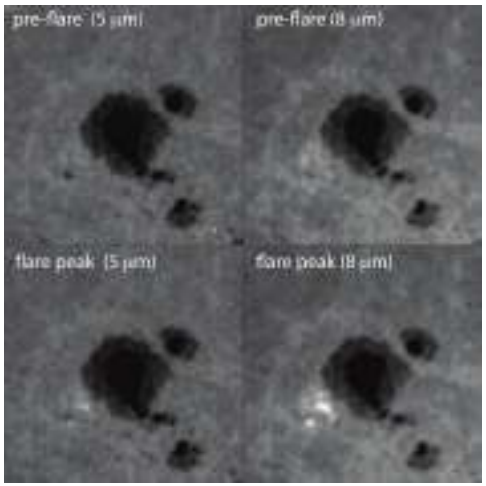
30 THz (10 μm), uncooled sensor, 17 arcsec spatial resolution.

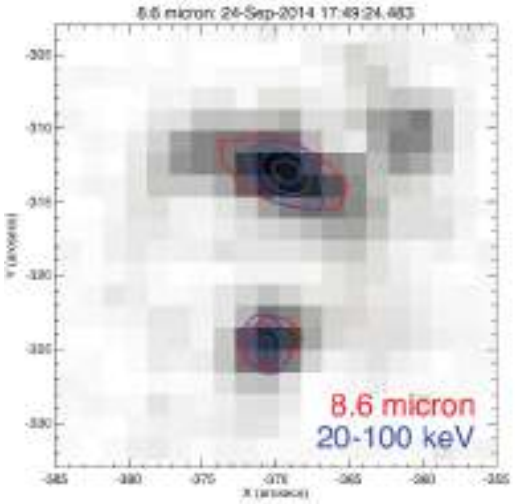




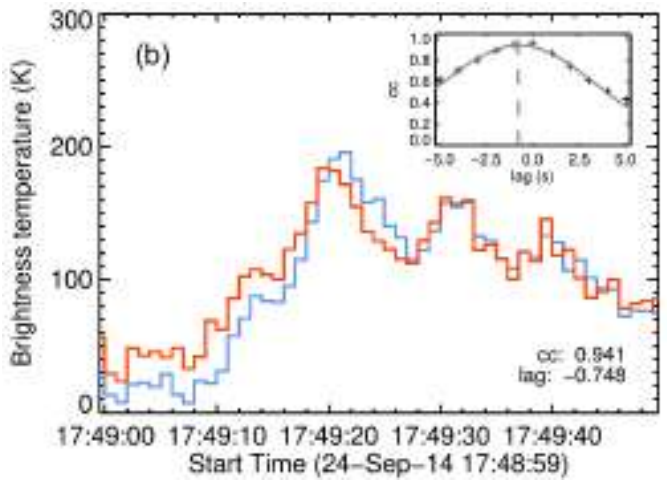
Giménez de Castro et al, 2018

36.5 & 57.6 THz (8.2 & 5.2 μm), QWIP sensor, 1.3 arcsec (@ 5.2 μm).



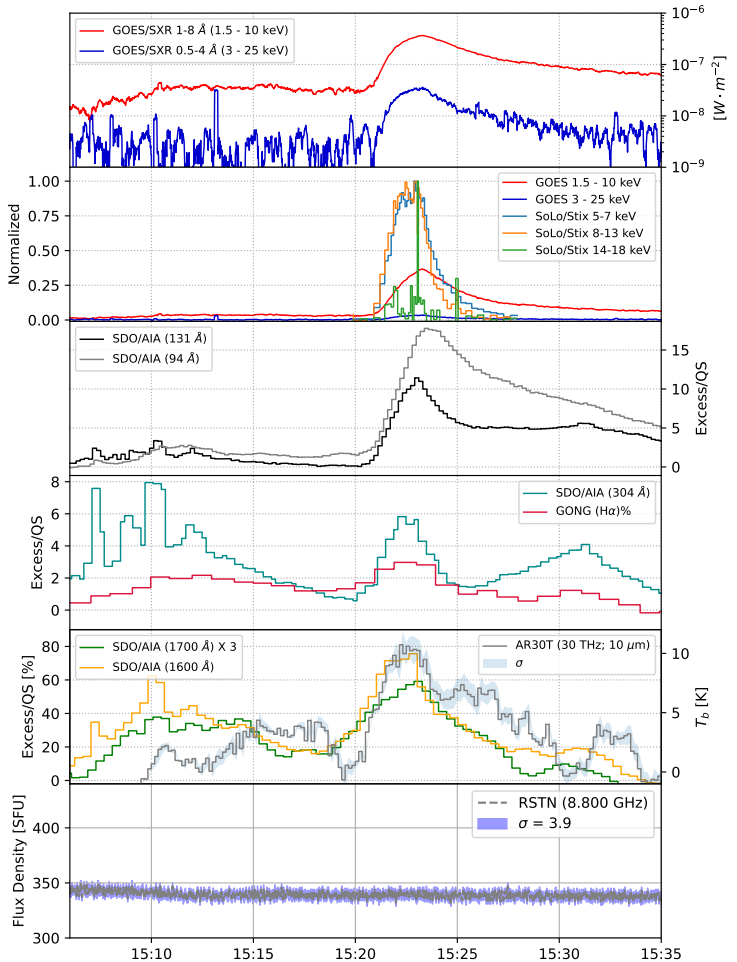


Penn et al, 2016



Simões et al, 2024

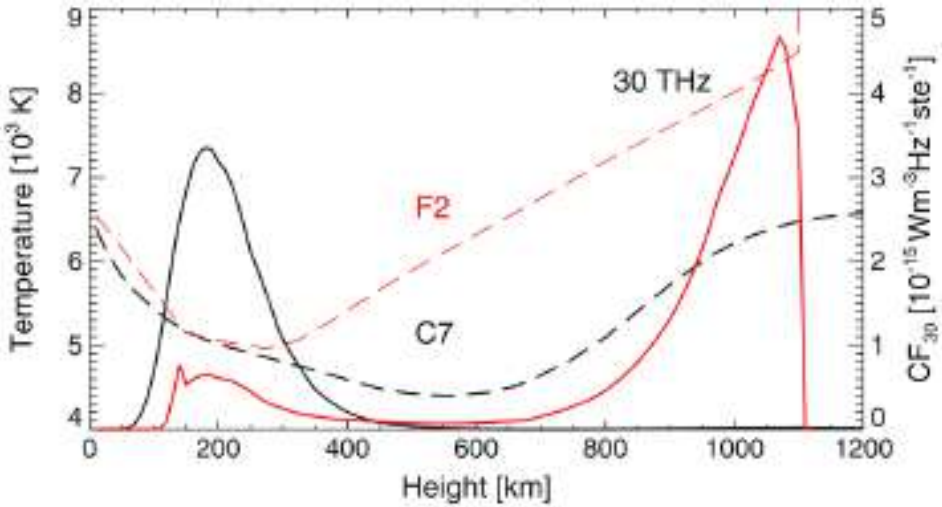
30 THz (10 μm), uncooled sensor, 13 arcsec spatial resolution.

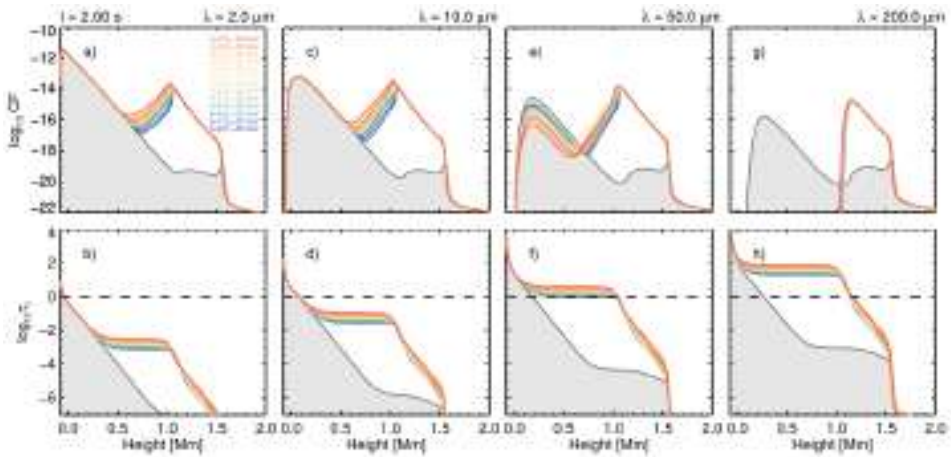


López et al, 2025 (*in preparation*)

Emission Origin at 10 μm

- The emission is consistent with thermal Bremsstrahlung of a heated plasma.
- The flaring site is $\approx$ 1000 km above photosphere





Trottet et al, 2015 Simões et al, 2017.

Energy Transport Mechanisms to the lower Chromosphere

- Accelerated charged particles as in Trottet et al, 2015
- Heat Conduction from the corona as in López et al, 2022
- Alfven waves as in Fletcher & Russell, 2013

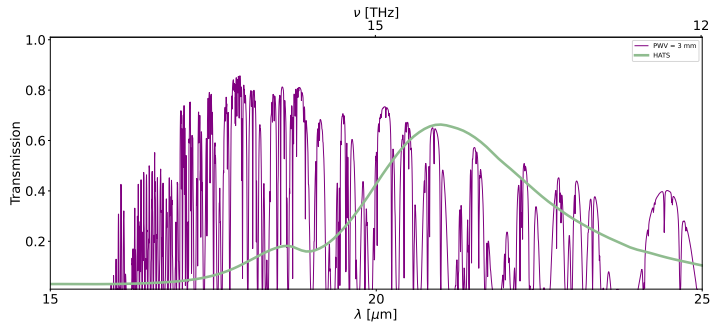
Present Instrumentation

The Solar Submillimeter Telescope (SST)

- Designed by CRAAM in the 1990s, installed at CASLEO (Argentina).
- In operation since 2001.
- $\lambda_1 = 1.4$ mm & $\lambda_2 = 0.7$ mm.
- **Only sub-THz solar telescope.**

High Altitude THz Solar photometer (HATS)

- Full Sun telescope with Golay cell sensor and passband filter.
- Central Wavelength: 20 μm (15 THz).
- Installed at 2,500 m.a.s.l. (OAFA observatory, Argentina)
- **Started regular observations on April 2025.**



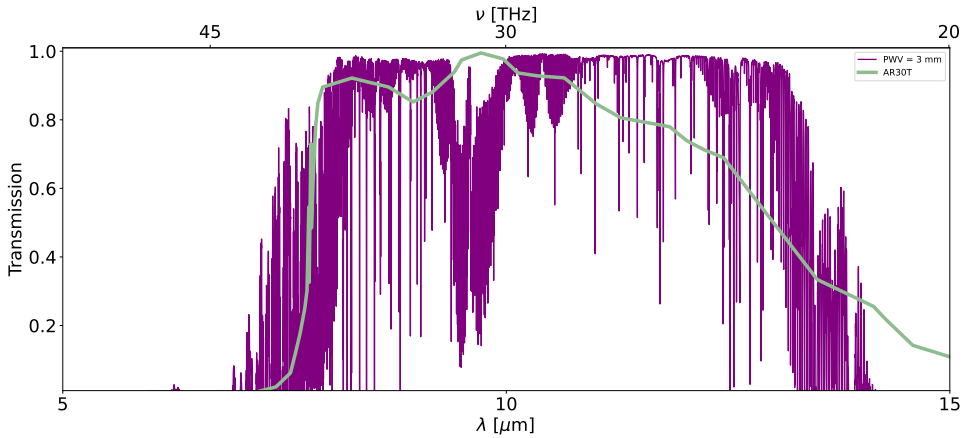
AR30T spectral response (green) and atmospheric transmission for PWV=3 mm (purple).

SP30T & AR30T

- SP30T
  - Installed at CRAAM HQ in São Paulo downtown.
  - Sensor: Thermovision FLIR Systems A20M camera,
  - Telescope: 15-cm aperture Newtonian
  - Collects the light from a Hale-type coelostat.
  - Central wavelength: (10 ± 2.5) μm
  - Diffraction limit: 17 arcsec (@ 10 μm)
  - FOV: full sun.
  - Operation Mode: Continuous observations strongly limited by overcast weather.
- AR30T
  - Installed at Felix Aguilar Astronomical Observatory (OAFA), 2500 masl, Argentina
  - Sensor: Thermovision FLIR Systems SC645 camera,
  - Telescope: 20-cm aperture Newtonian
  - In *piggy-back* of Hα Solar Telescope for Argentina (HASTA)
  - Central wavelength: (10 ± 2.5) μm
  - Diffraction Limit: 12.5 arcsec (@ 10 μm)
  - FOV: $\approx$ 60% of Sun Disk
  - Operation Mode: Continuous observations limited to *in-situ* operator.

SP30T & AR30T

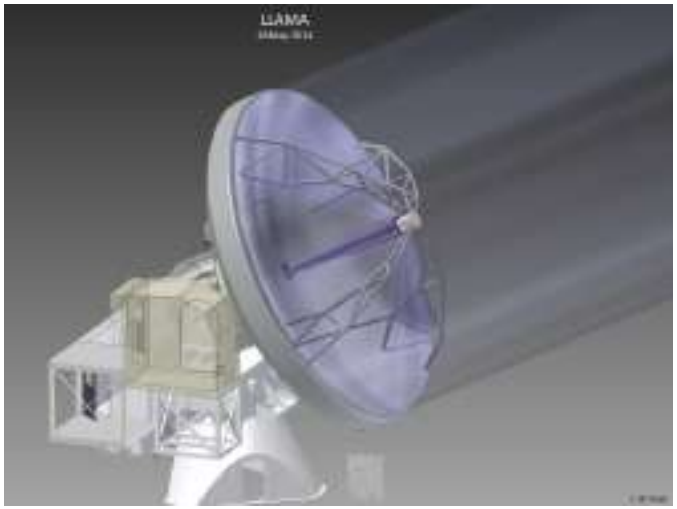
AR30T SP30T



AR30T spectral response (green) and atmospheric transmission for PWV=3 mm (purple).

Future Instrumentation

Large Latin American Millimeter Array



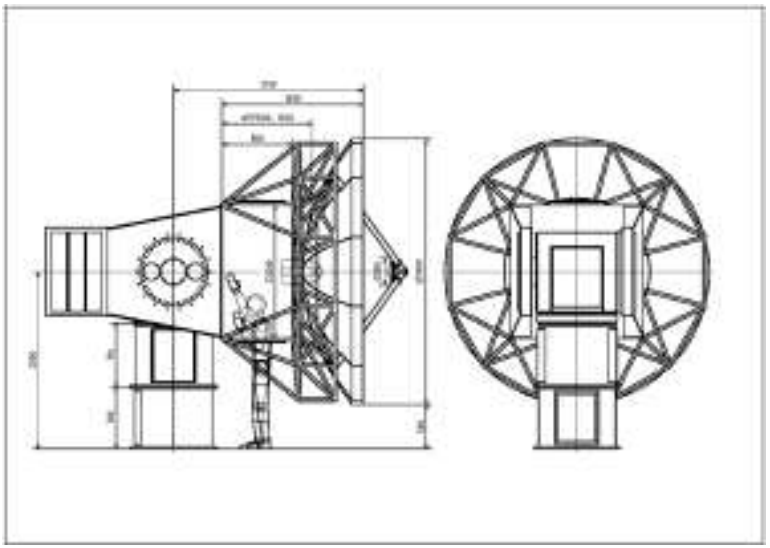
- Single dish antenna,12 m aperture, 2 Nasmyth+Cass, Vertex.
- Alto Chorrillos site (4.8 km asl)
- Observes at several bands simultaneously.
- Spectrometer, resolution $\sim$ 40 KHz & 4 GHz instantaneous band.
- Science solar cases: solar cycle, quiescent structures, sub-THz lines, flares.
- Beginning of observations: not before 2024.

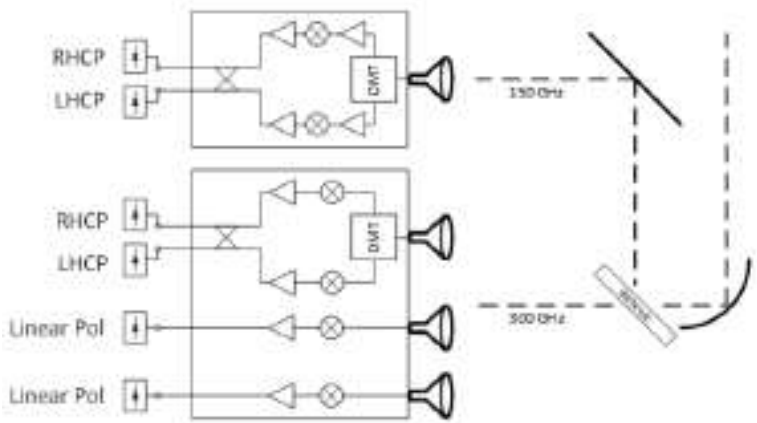
Spectral bands:

- 5: 157 GHz (1.910 mm) – 212 GHz (1.415 mm)
- 9: 602 GHz (0.498 mm) – 720 GHz (0.417 mm)
- 6: 211 GHz (1.421 mm) – 275 GHz (1.091 mm)
- 2+3: 67 GHz (4.480 mm) – 116 GHz (2.586 mm)
- Room for 2 more bands (Nasmyth cabins)
- Room in the Cass focus.

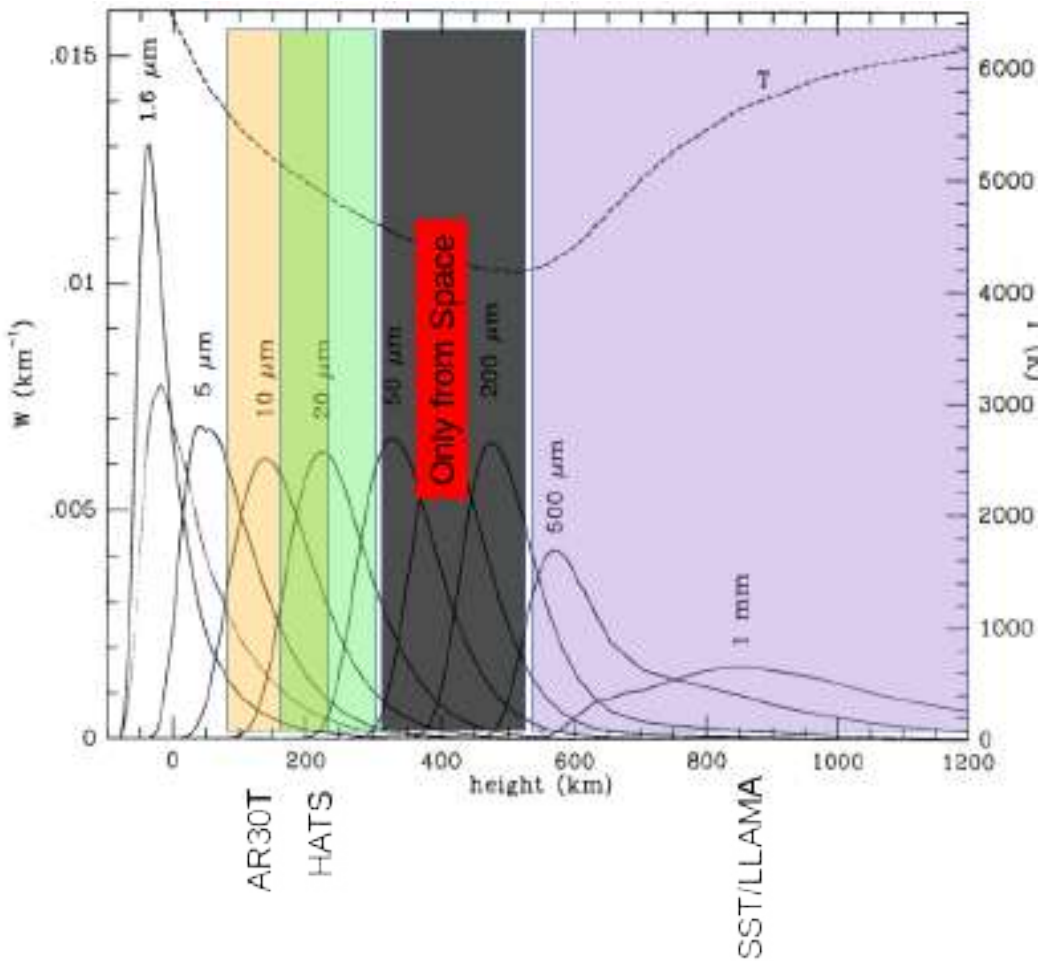
SST next generation

- Multibeam 150 & 300 GHz.
- 3 m antenna.
- Circular polarization in both bands.
- Spectrometer.
- Expected sensibility: **C** to **B** –class flares.





Instrumentation: All in all



Weighting functions versus height for several wavelengths. Dot curve is VAL-C atmosphere model. Colored areas identify spectral ranges of the different instruments.

Solving the Quiz

How are white light flares produced?

The only way to have an answer is to increase the spectral coverage and the spatial resolution and having polarization information.

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