Solar radio observations and space weather

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What this talk is NOT about

Space weather focuses on the understanding and forecasting of solar activity for **operational** purposes

- empirical quantities that are easily accessible (**proxies**) are often preferred to physical variables that require post-processing
- empirical and semi-empirical models often are frequently used
- **long-term records** are important for carrying out statistical studies

Solar radio emissions are both a **powerful diagnostic**

and a **major nuisance** for telecommunications

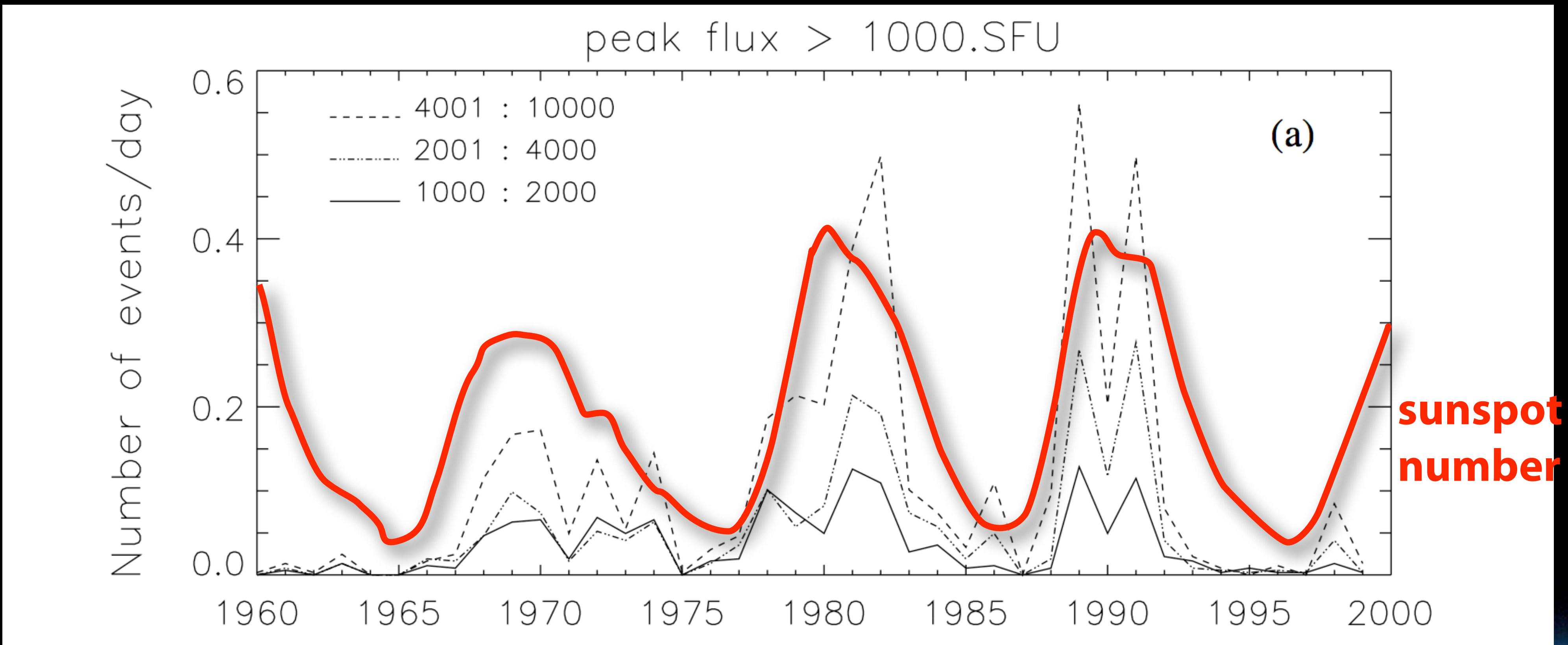


Figure 3. Total number of events/day as a function of time in years (a) for peak flux $>10^3$ SFU and (b) for peak flux $>10^4$ SFU. The frequency ranges are 1–2, 2–4, and 4–10 GHz.

Bala et al., Radio Science (2002)
Frequency of radio bursts that are likely to affect wireless communications

Where radio observations can contribute to space weather applications

mm

- microwave emissions
  - tracers for short- and long-term solar activity

m

- decimetric-metric emissions
  - coronal type III and type II emissions as tracers for CME liftoff
  - characterisation of Solar Energetic Particle (SEP) acceleration sites
  - location of coronal holes
  - (Interplanetary Scintillations)

km

- emissions below ionospheric cutoff
  - type II emissions as tracers for the propagation of interplanetary CMEs

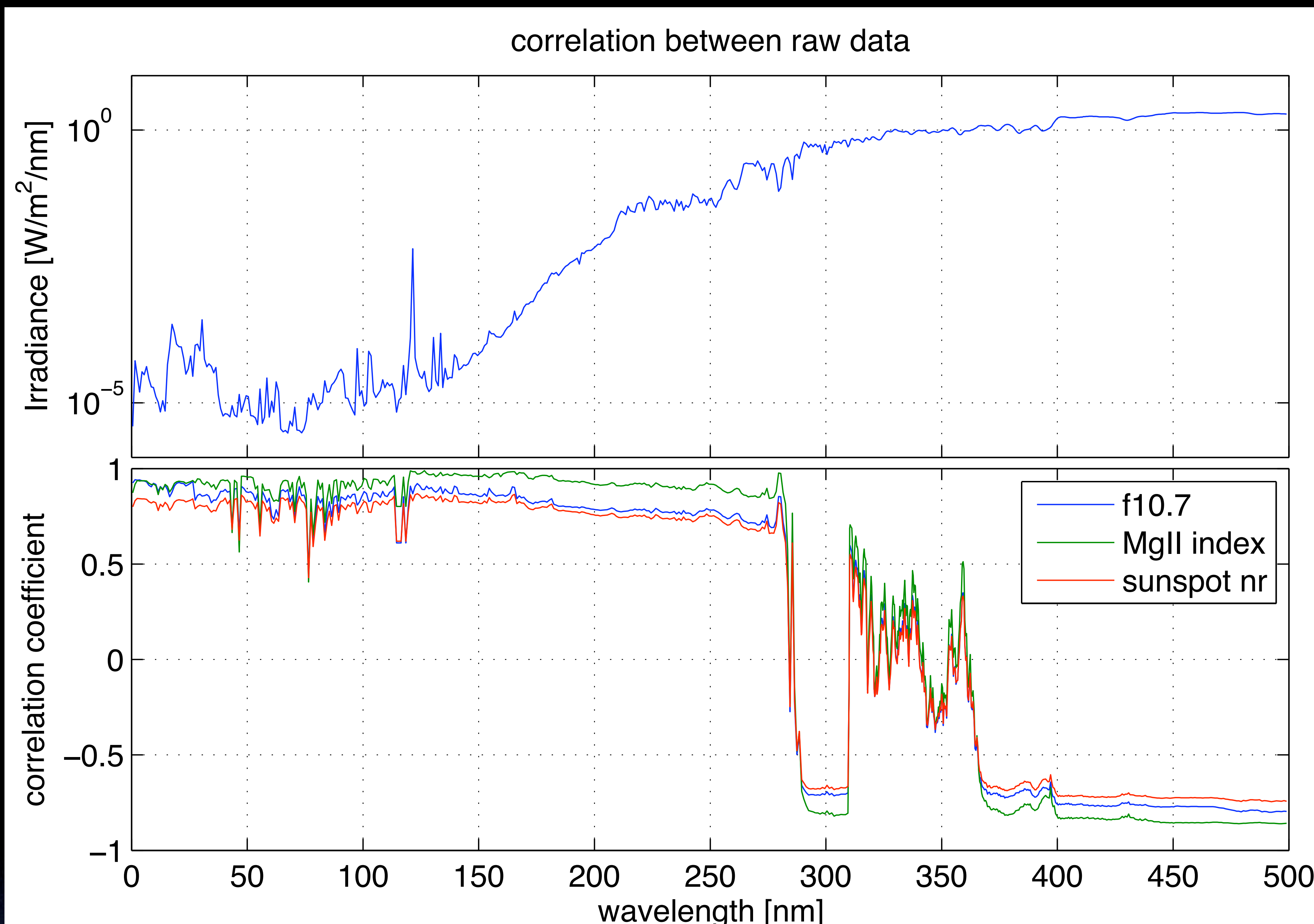
Proxies for solar activity

- The solar microwave flux is widely used as a **proxy for solar irradiance**

- The **flux at 10.7 cm** is still by far the most widely used gauge of solar activity
  - continuous measurements since Feb. 1947
  - relatively easy to measure : few calibration or site choice problems
  - no latency in measurement

- But there are several other (and often better) proxys around

Proxies for solar activity



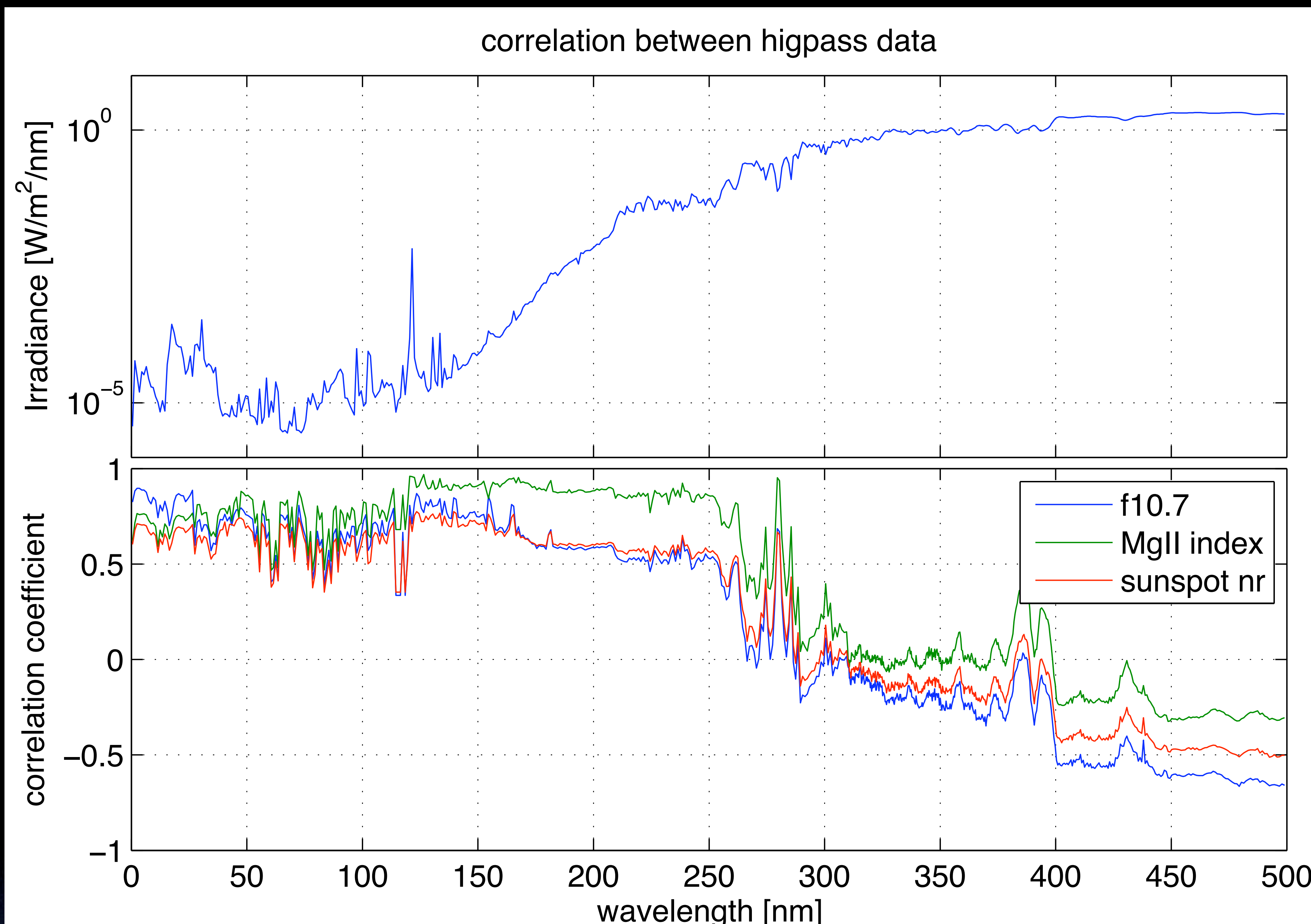
solar spectral irradiance

correlation with solar proxies

correlation based on 6 years of data (specta are from SORCE)

Proxies for solar activity

***** Same plot as before, but only for variations < 80 days *****



solar spectral irradiance

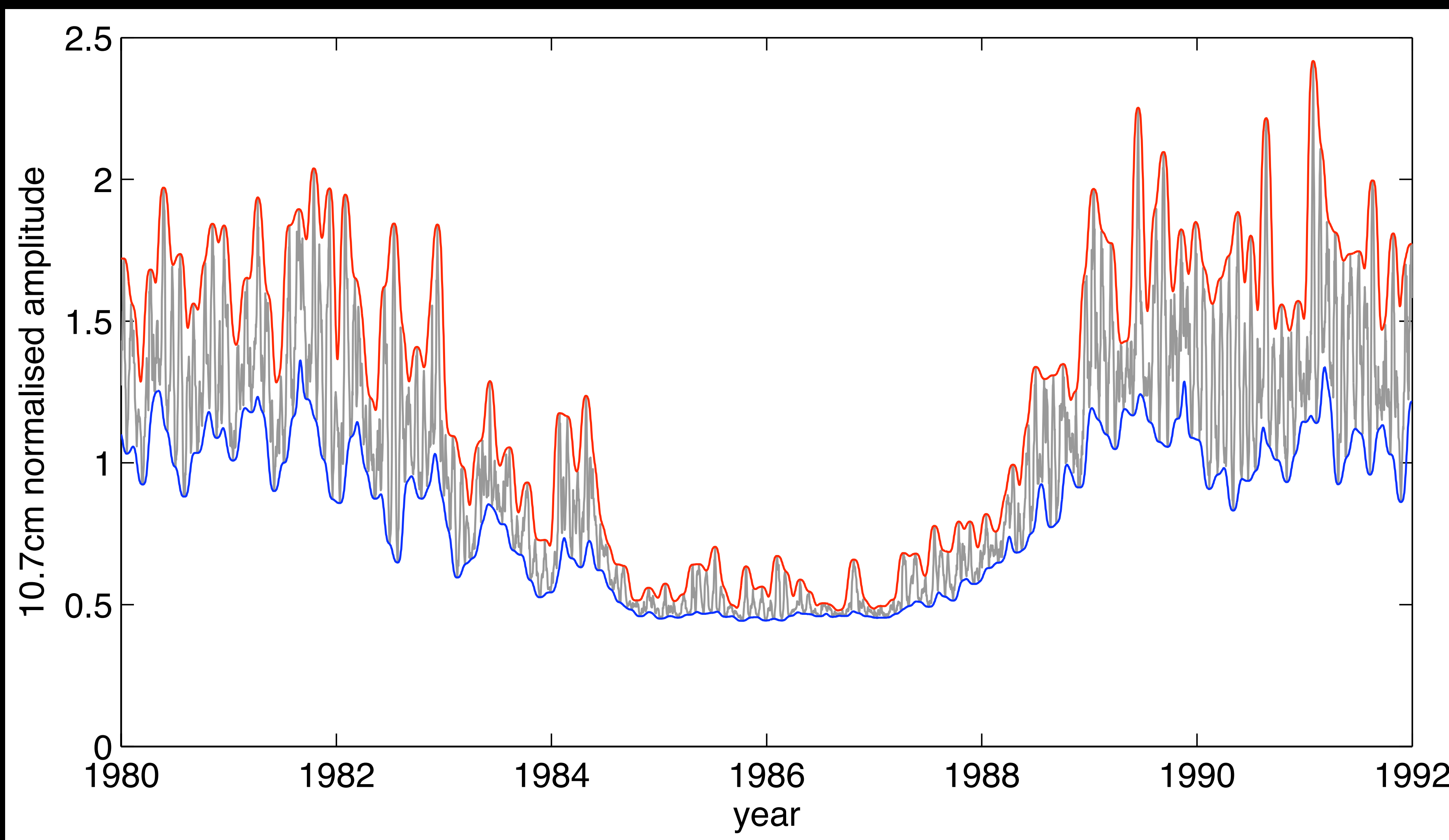
correlation with solar proxies

The flux at 10.7 cm

- The radio flux at 10.7 cm is used as ***THE*** solar input in many ionospheric/thermospheric/atmospheric specification models
- It is a good all purpose solar proxy
- But attempts to provide a better description of the solar spectral variability have failed

Why is the 10.7 cm flux such a good proxy ?

radio flux @ 10.7 cm



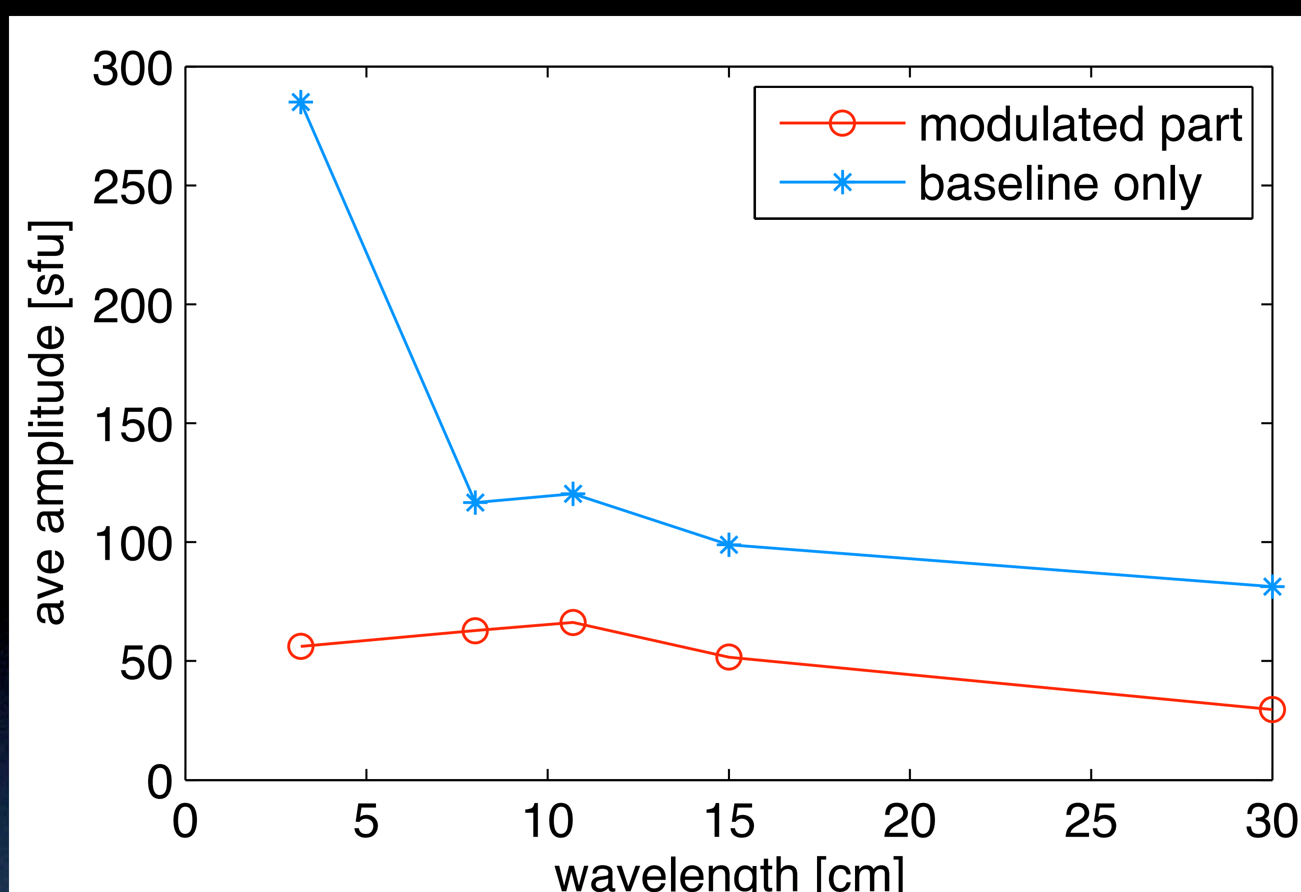
envelope = modulation due to solar rotation

baseline = «quiet Sun»

Thermal bremsstrahlung or gyroresonance ?

- What is the origin of the cm flux ?
  - thermal bremsstrahlung = optically thin corona
  - gyro-resonance emission = optically thick sunpots

- Both types of emissions coexist with a wavelength-dependent ratio
  [Tapping 1987, Schmahl & Kundu, 1985]



mostly bremsstrahlung (plages and faculae)

mostly gyro-resonance emission (sunspots)

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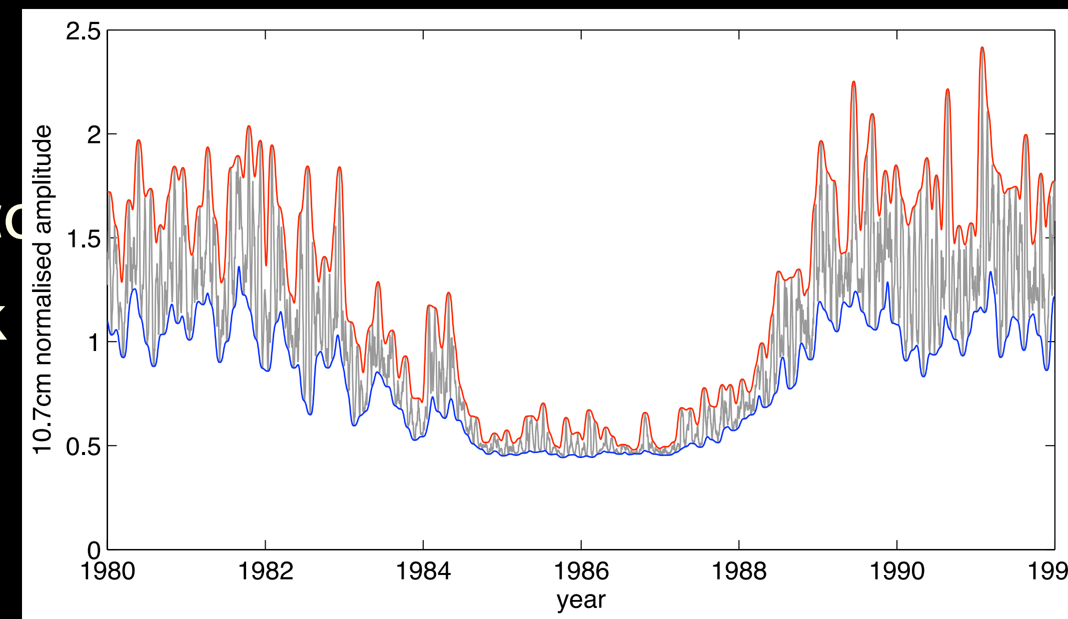

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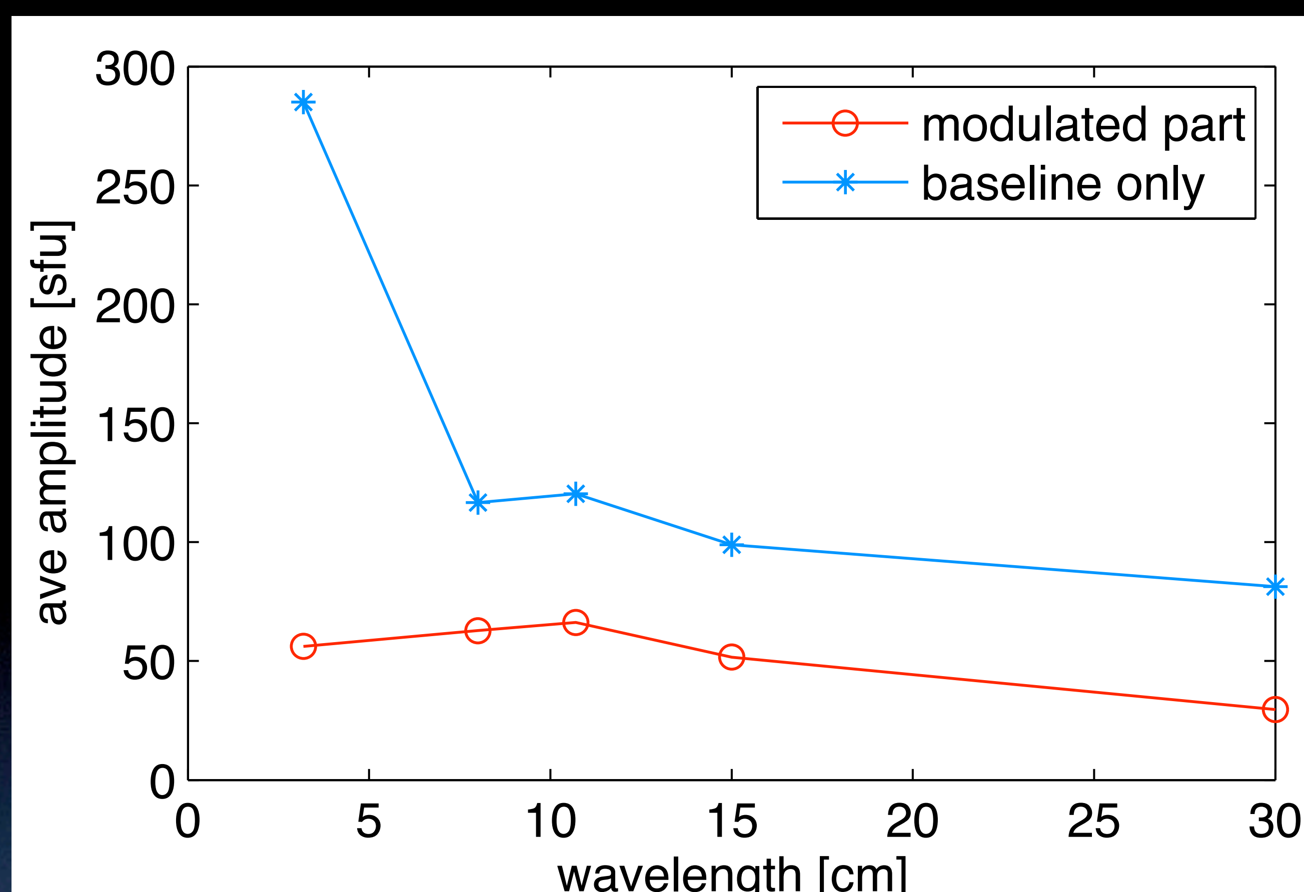
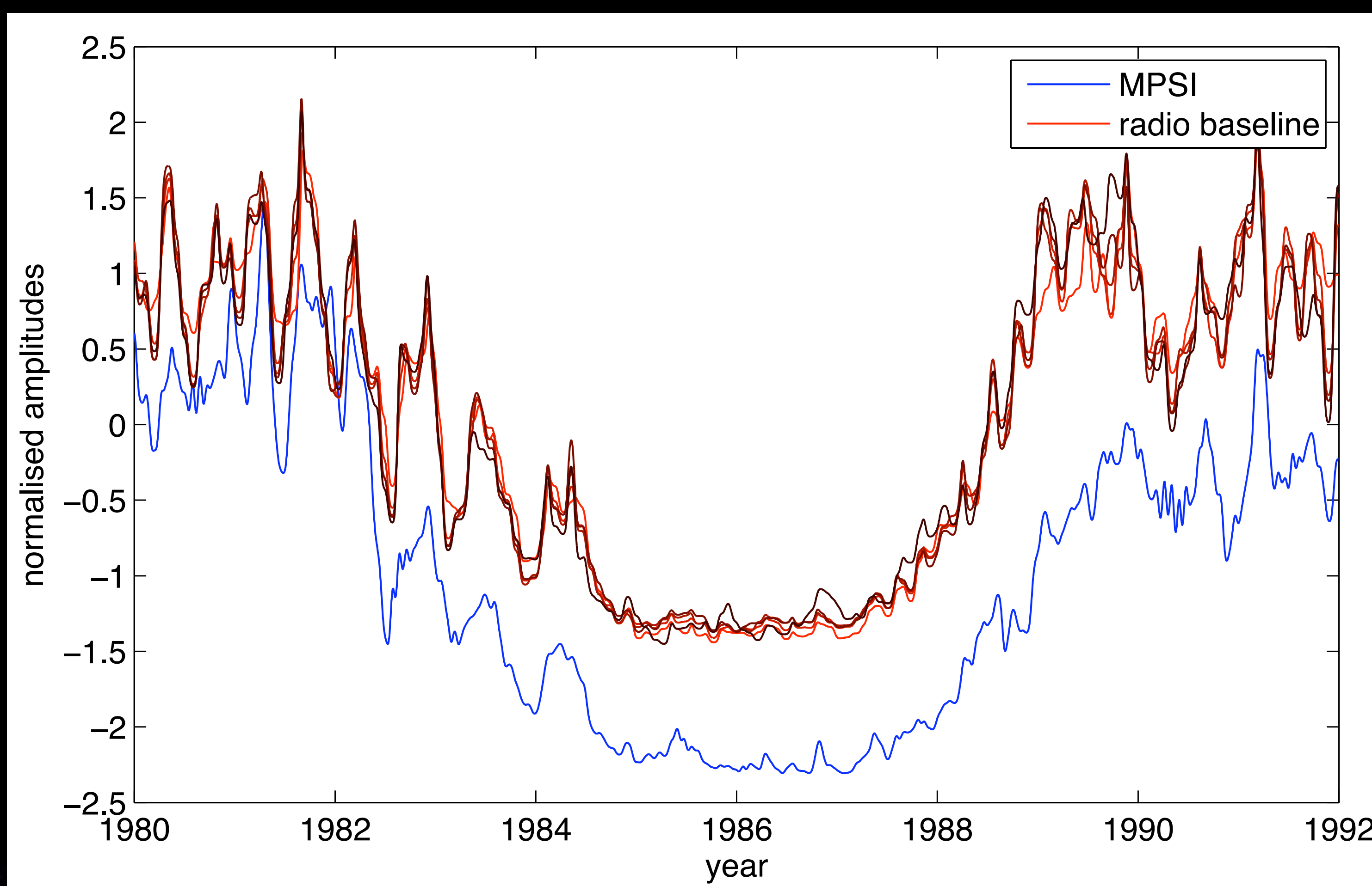


mostly bremsstrahlung (plages and faculae)

mostly gyro-resonance emission (sunspots)

Thermal bremsstrahlung or gyroresonance ?

- The **baseline** of the radio flux is most strongly correlated with indices that quantify plages and faculae (MgII index, CaK index, MPSI)

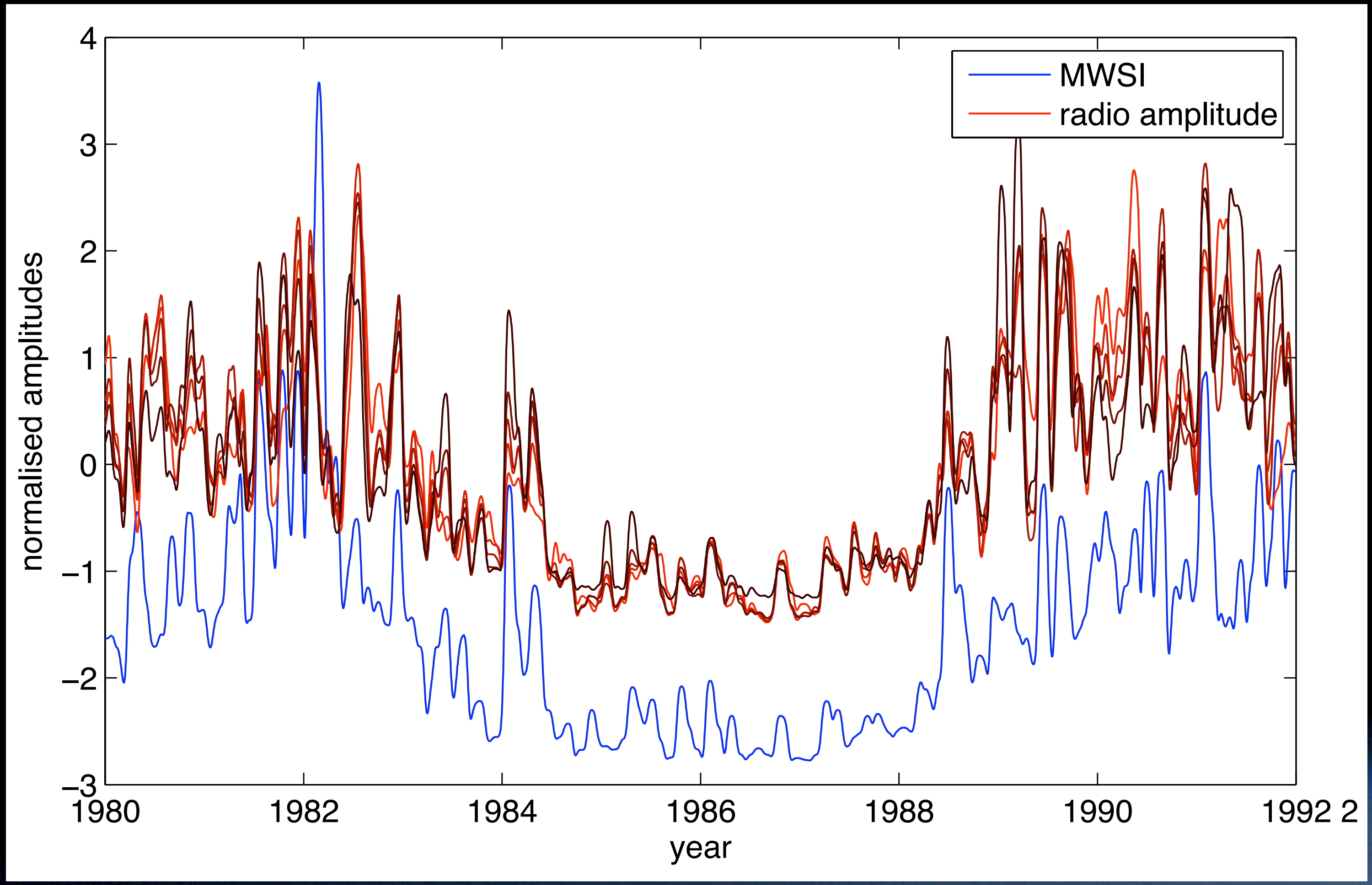


radio flux @ different wavelengths (Toyokawa Obs.)

Magnetic Plage Strength Index (MPSI)

Thermal bremsstrahlung or gyroresonance ?

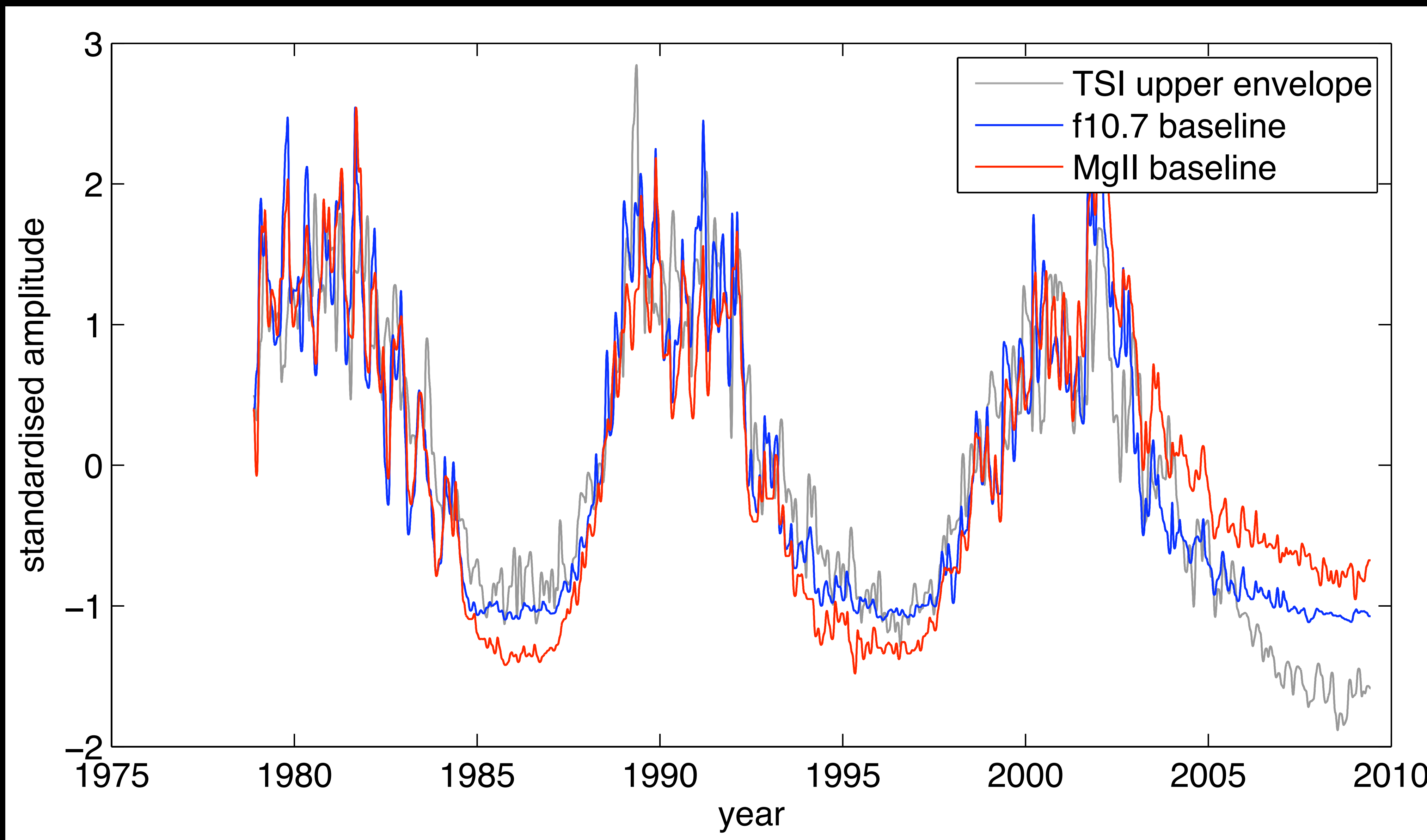
- The **envelope** of the radio flux is most strongly correlated with indices that quantify sunspots (sunspot index, MWSI)



radio flux @ different wavelengths (Toyokawa Obs.)

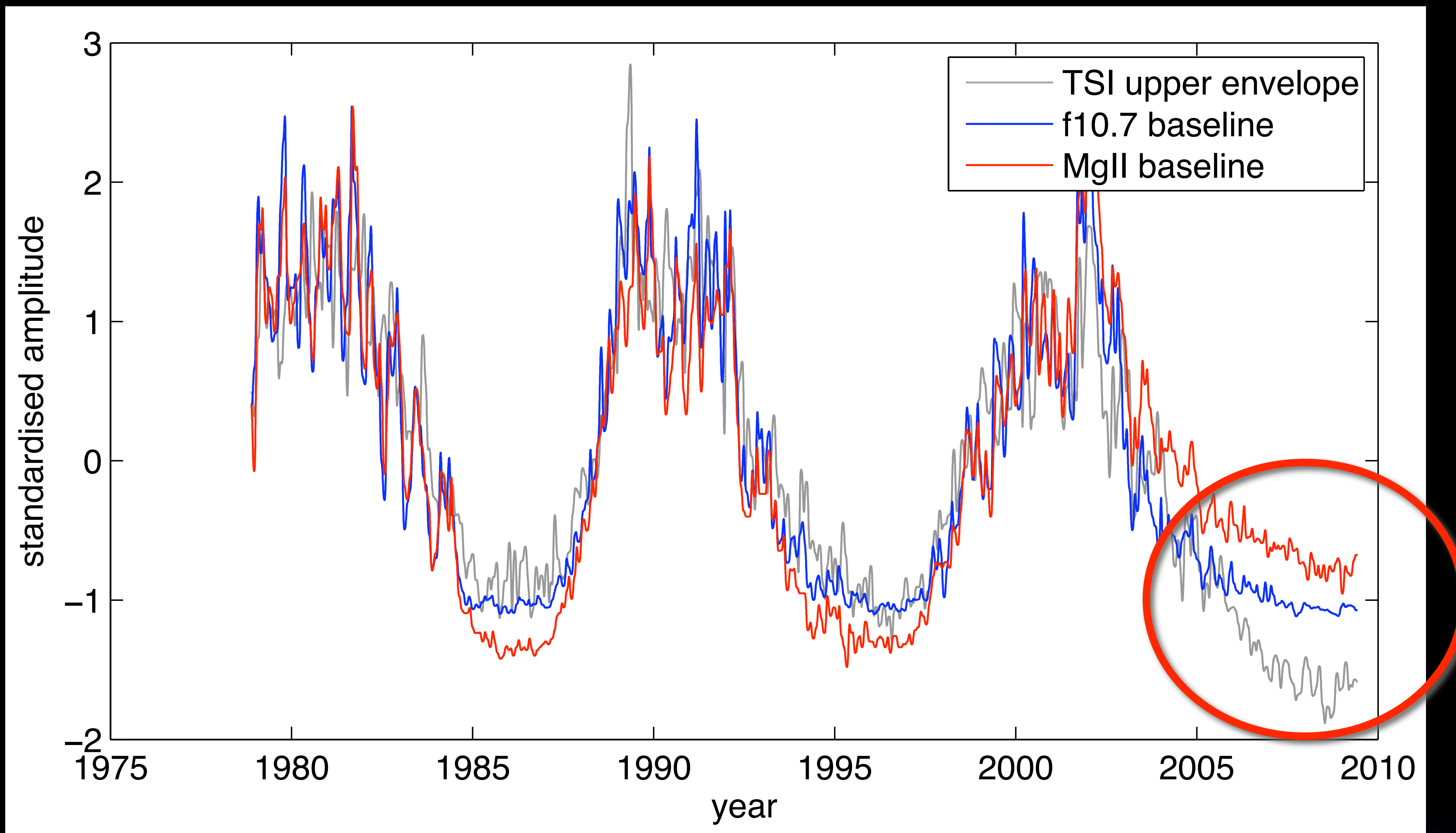
Mount Wilson Sunspot Index (MWSI)

Comparison with other «quiet Sun» proxies



The present solar minimum definitely differs from the two preceding ones

Comparison with other «quiet Sun» proxies



The present solar minimum definitely differs from the two preceding ones

Conclusions (1)

- For practical and physical reasons, the solar radio flux at 10.7 cm remains an excellent all-purpose solar activity proxy
- **Synoptic observations** at different wavelengths (ideally 3 & 10.7 cm) allow to partly separate the different contributions
  - Both can be measured at Nançay
- **Long-term** and well calibrated observations are vital [Tanaka et al., 1973]

Other uses of solar radio observations

Decametric emissions and CMEs

- Radio observations of the limb are useful for characterising CME liftoff (= early warning) before coronagraph observations take over.

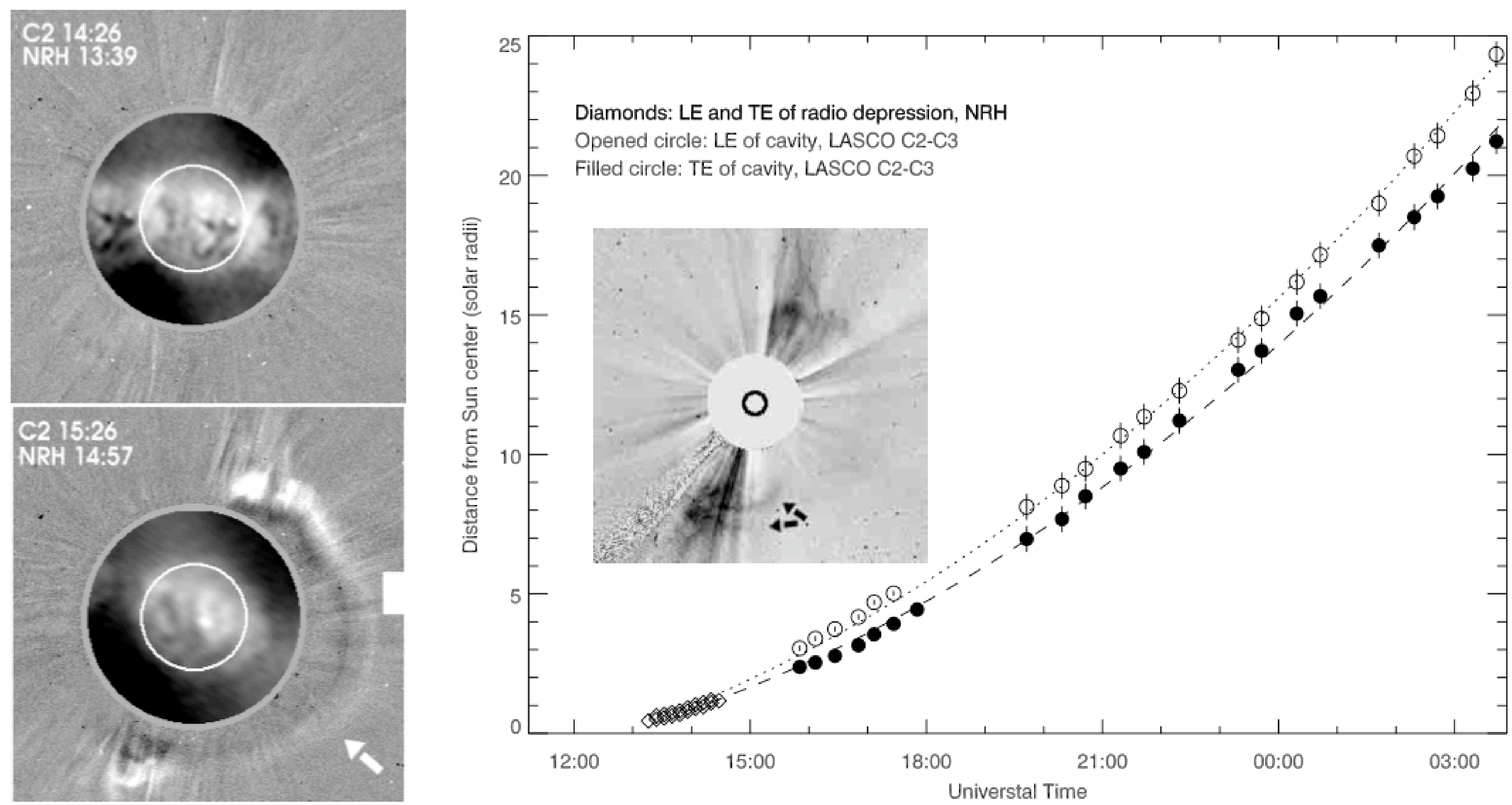


Fig. 7. Left panel: upper image presents a pre CME high solar corona. The lower image shows the expansion of the halo CME seen in LASCO-C2 coronagraph, and pointed out by the white arrow. The CME is mainly expanding westward as expected by the orientation of the filament. Right panel: height/time plot of the structure pointed out in the inner C3 image with black arrows, compared to the evolution of the radio depression associated with the filament.

Marqué et al., ApJ (2002)

Decametric emissions and CMEs

- Advantages for space weather
  - High cadence, no latency
  - Ideal for observations on the disk (detection of halo CMEs)
- Disadvantages
  - Need 3 similar instruments worldwide to have continuous coverage
  - Post-analysis is needed to robustly infer CME characteristics

Coronal hole location

- The location of **coronal holes** is important for determining the impact of fast solar streams (= major cause of instrument failures)
- Decametric radio observations are a complement to EUV imaging
- Advantage : complement to EUV observations

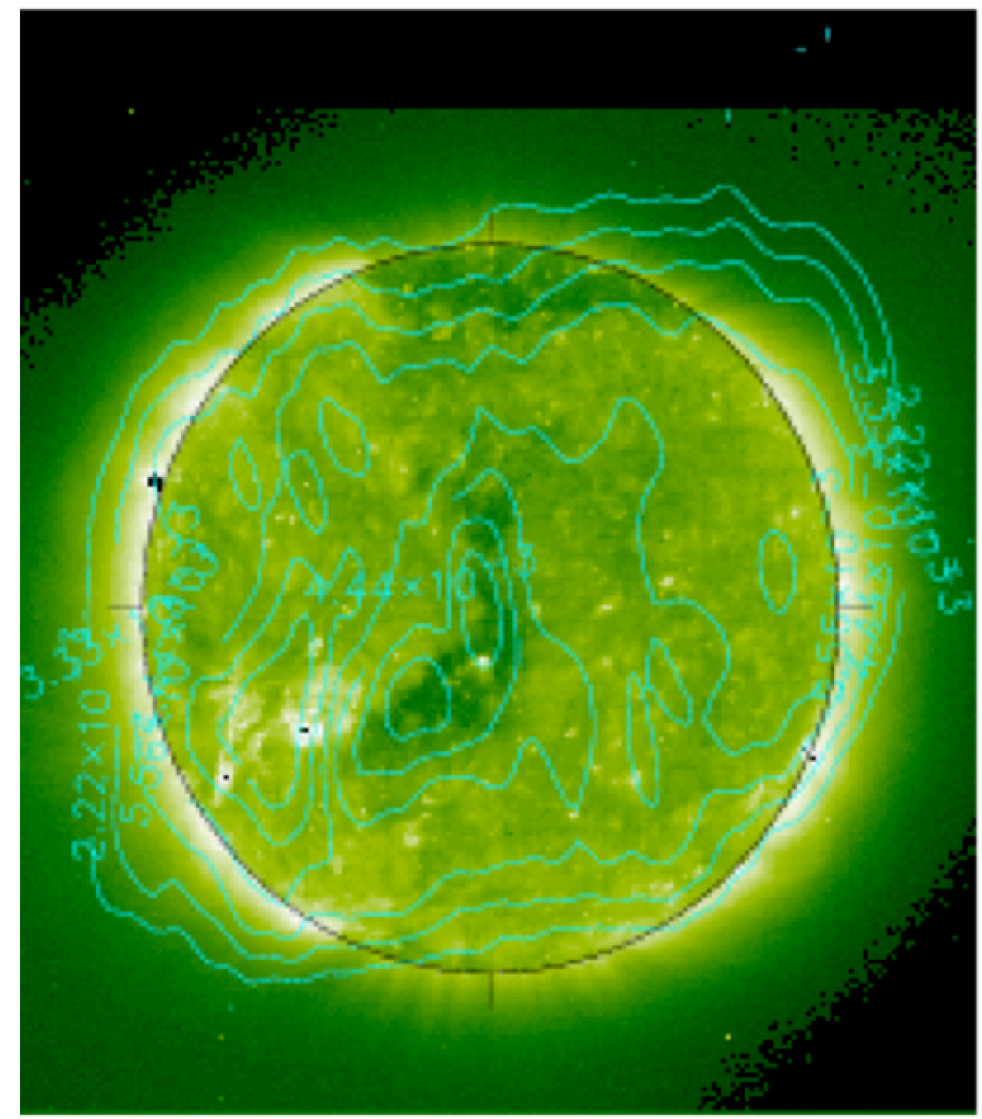
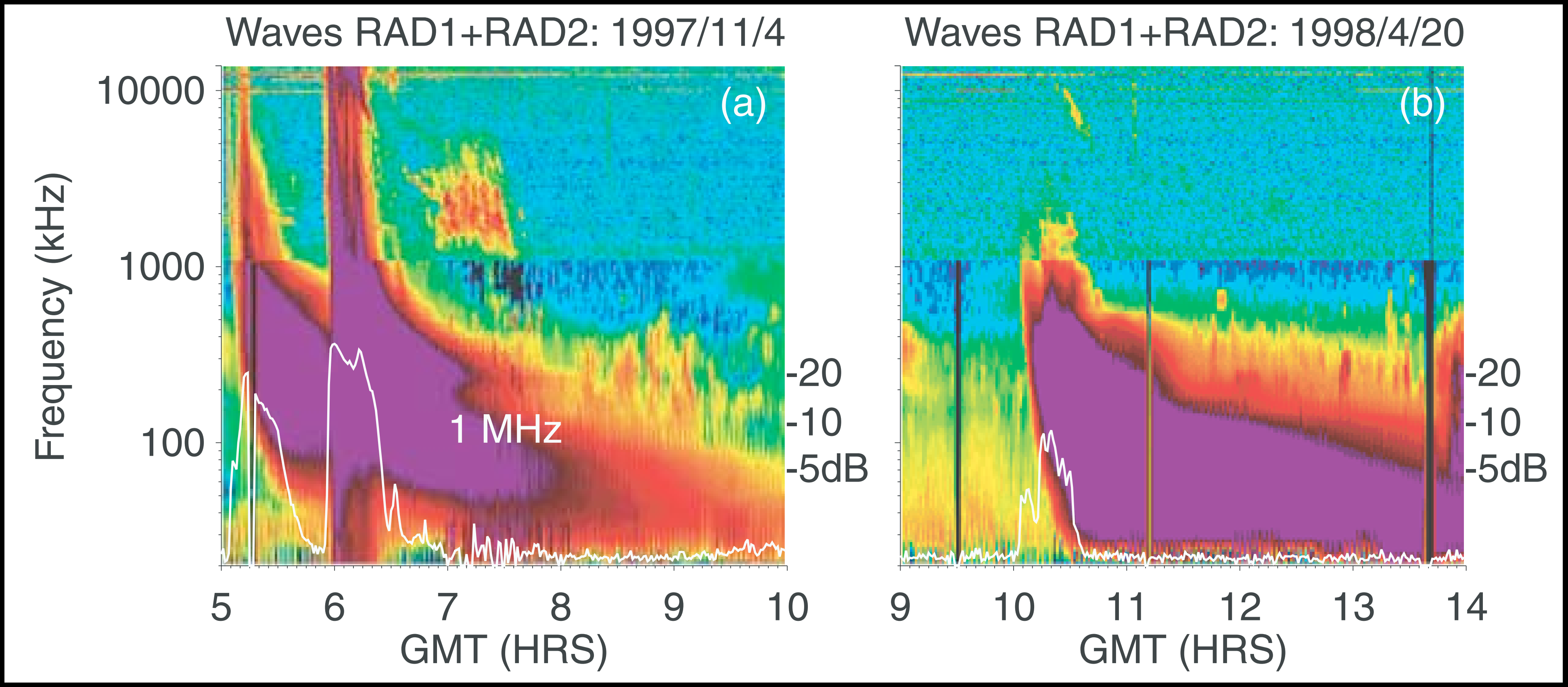


Fig. 2. Contours of radio brightness temperature at 410 MHz superimposed to the EIT image taken in the 195 Å filter at 21:00 UT; the small disalignement between the two images is due to the time difference between the observations ($\simeq 6^h$).

Chiuderi-Drago et al. A&A (1999) emissions at 410 MHz are overlaid

Type III emissions and SEPs

- Long duration type III radio bursts are usually associated with Solar Energetic Particle (SEP) events [Cane et al., 2002; MacDowall et al., 2003]



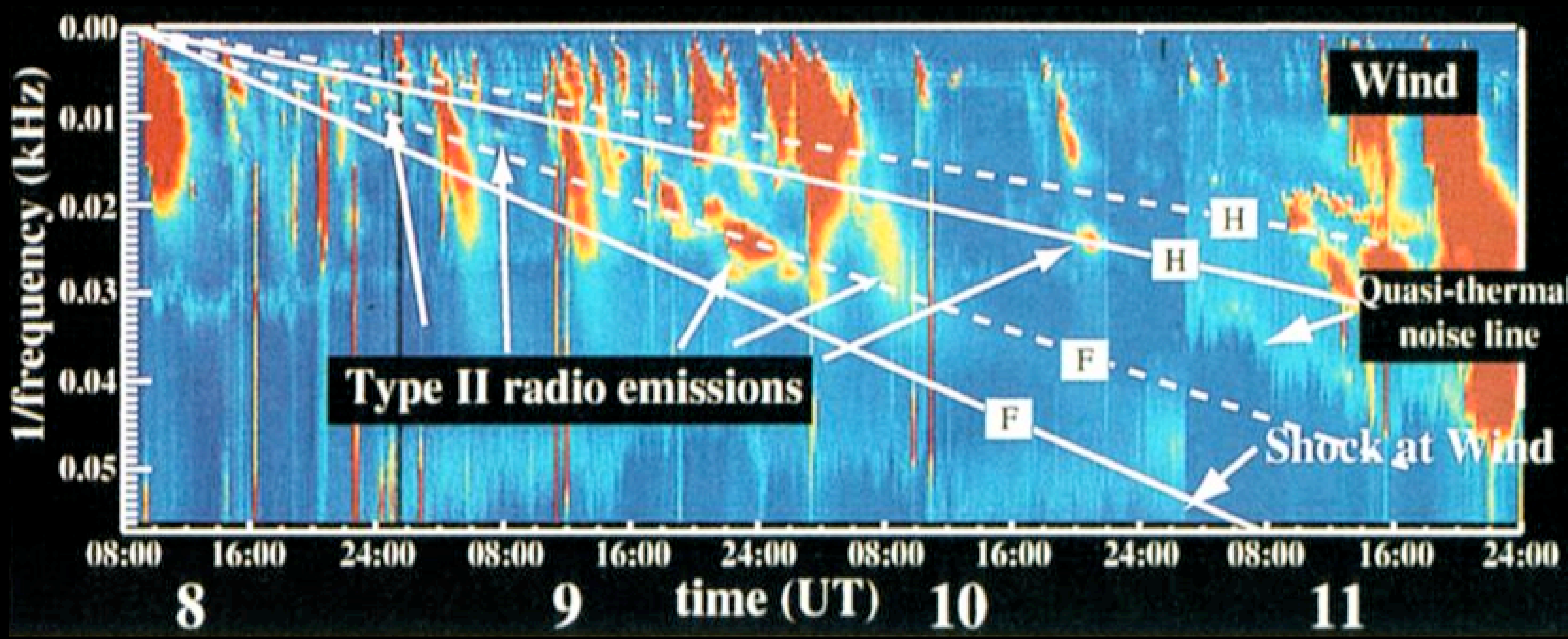
MacDowall et al., GRL (2003)

Type III emissions and SEPs

- Advantages
  - type III bursts are tracers of SEP propagation and intensity [talk by L. Klein]
- Disadvantages
  - geoeffectiveness of SEP does not solely depend on solar acceleration process
  - same as for CME tracking

Interplanetary shocks

- Interplanetary type II emissions are the signature of approaching interplanetary perturbations
- But this technique is not fully safe: not all perturbations have a clear radio signature...



Reiner et al., JGR (2001)
Dynamic spectrum of 8 Feb. 2000 event

Automatic recognition

- An important issue is the robust and **automatic detection** of specific radio signatures

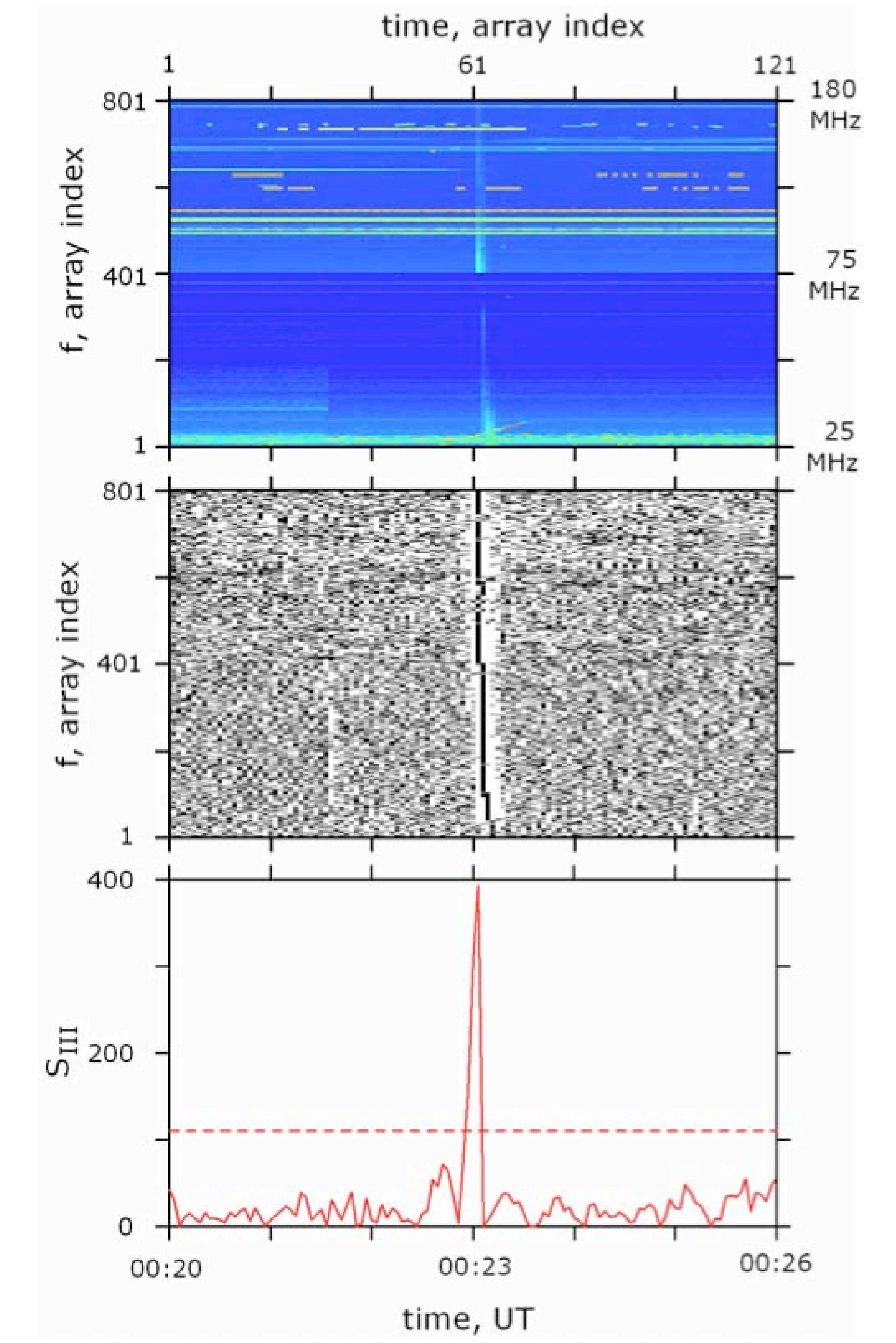
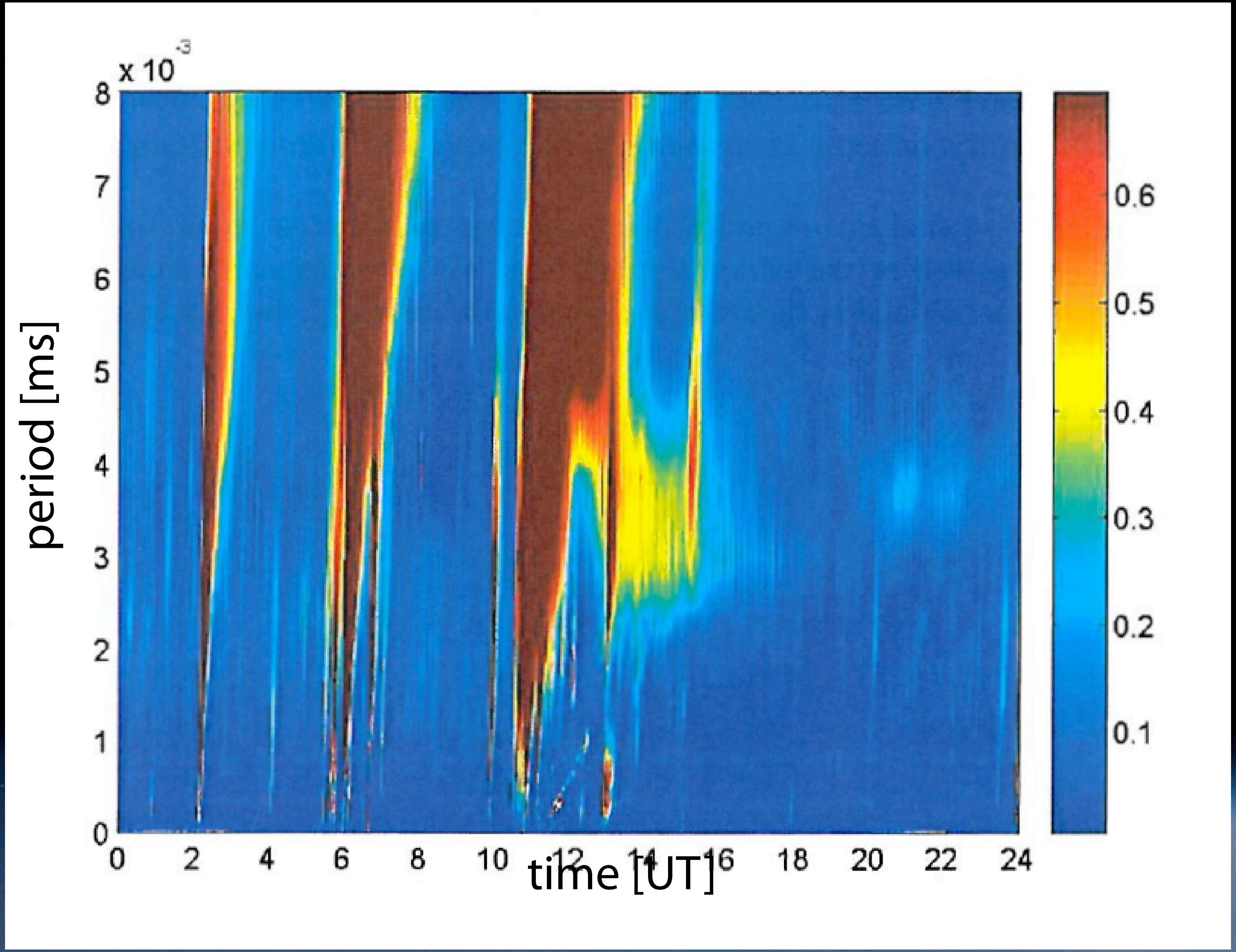


Figure 1. (top) Dynamic spectrum $G(i_t, i_f)$ of a single type III radio burst observed on 20 July 2002 at 0023 UT. (middle) The corresponding binary image $B(i_t, i_f)$. Pixels are black where $B = 1$ and white for $B = 0$. (bottom) Profile of S_{III} (solid line) versus time and the threshold level (dashed line).

Lobzin et al., Space Weather (2009)
Automatic detection of a type III burst

Automatic recognition

- An important issue is the robust and **automatic detection** of specific radio signatures



Tamaazousti & DdW (2008)
Automatic detection of a type II burst from WIND dynamic spectra (22 March 2002)

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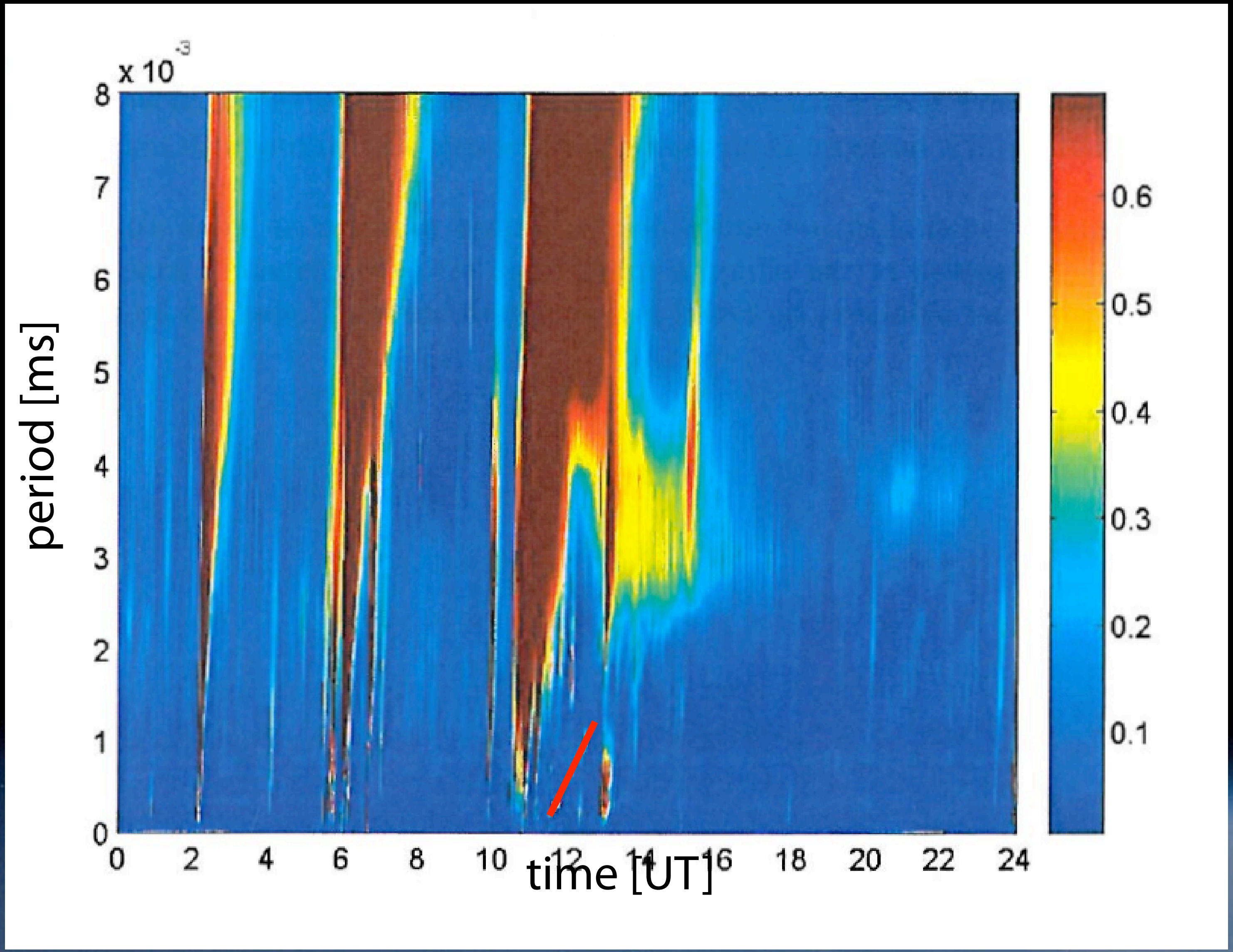

Conclusions (2)

- Radio imaging in the metric/decimetric range is a useful complement for diagnosing 1) CME liftoff, 2) coronal holes and 3) SEPs
  - but the transition to an operational tool still requires considerably more work
- Dynamic spectra < 10 MHz are a powerful diagnostic for impending shocks
  - but they are not fully reliable
  - (need more sensitive detectors)