Microwave Emission and the Solar Cycle

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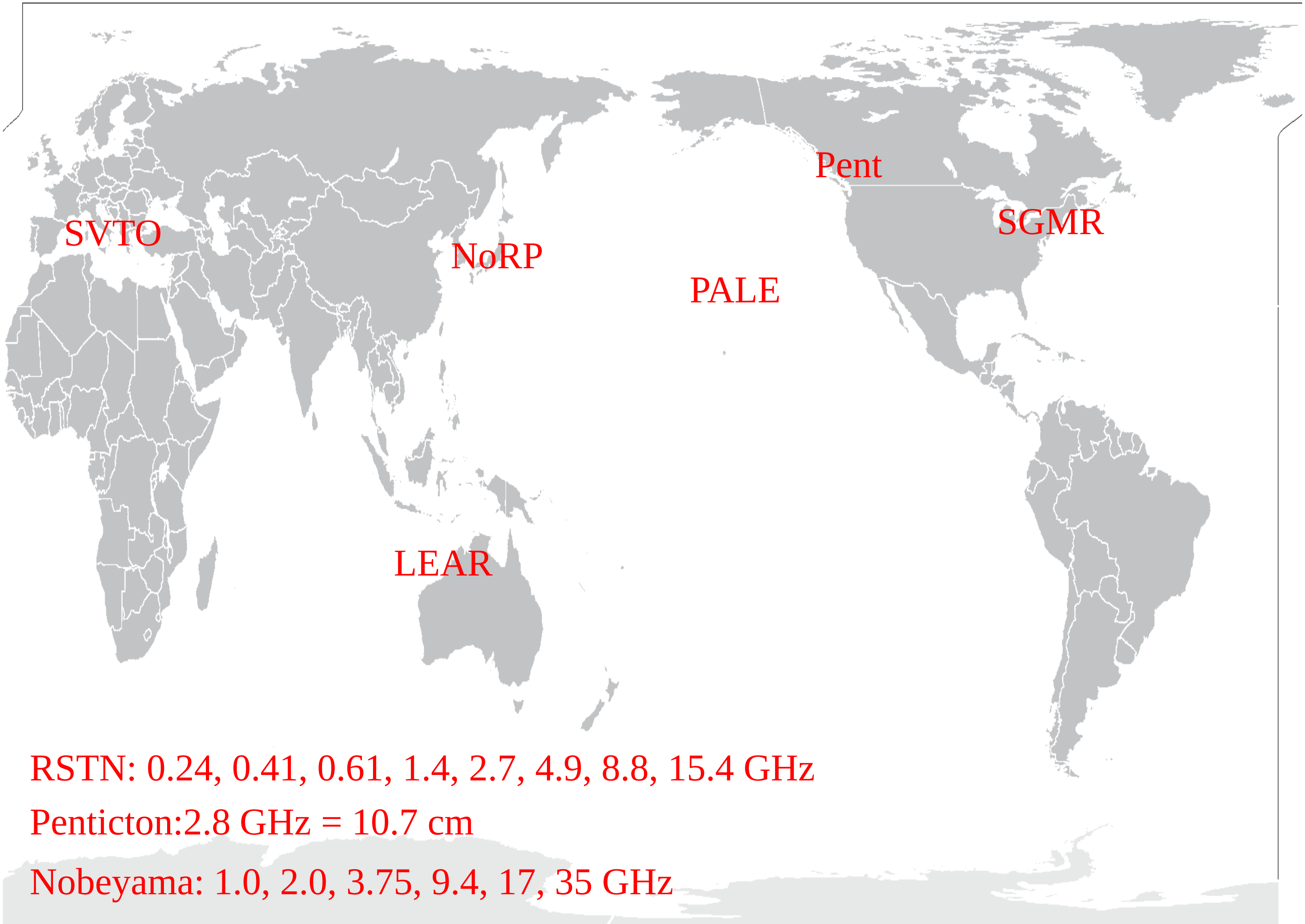
Solar radio monitoring



RSTN: 0.24, 0.41, 0.61, 1.4, 2.7, 4.9, 8.8, 15.4 GHz

Penticton:2.8 GHz = 10.7 cm

Nobeyama: 1.0, 2.0, 3.75, 9.4, 17, 35 GHz

ABSOLUTE CALIBRATION OF SOLAR RADIO FLUX DENSITY IN THE MICROWAVE REGION

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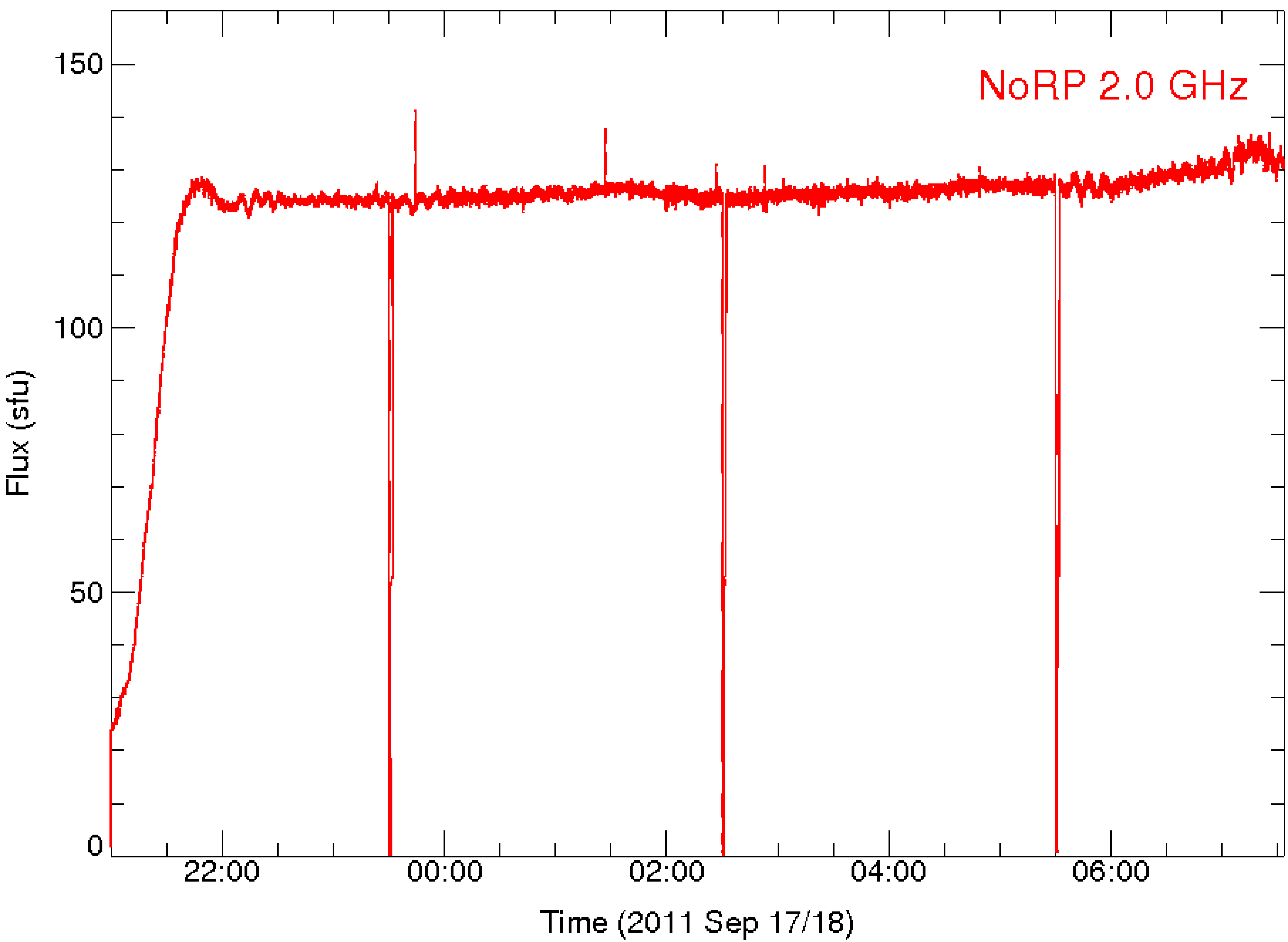
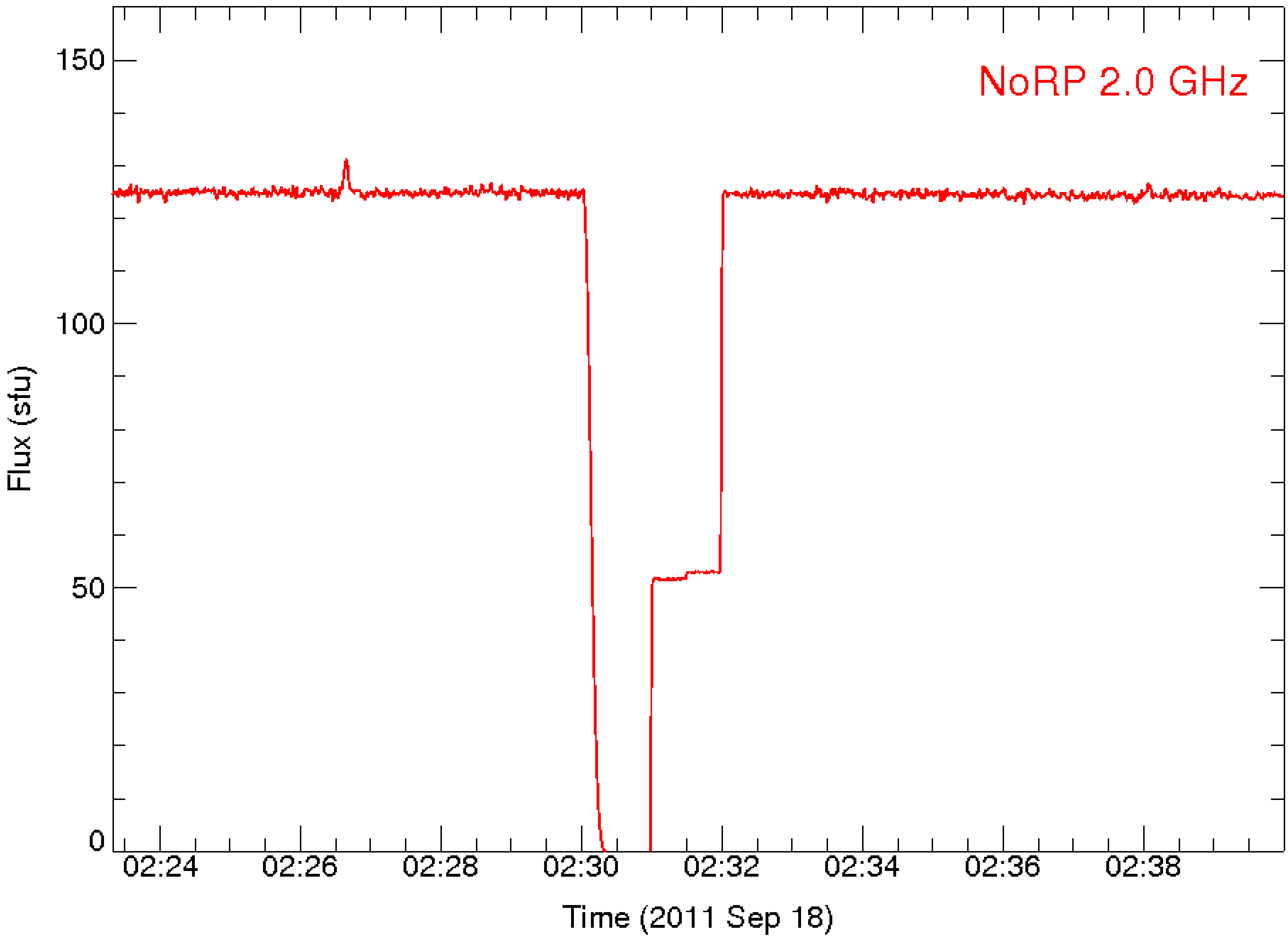
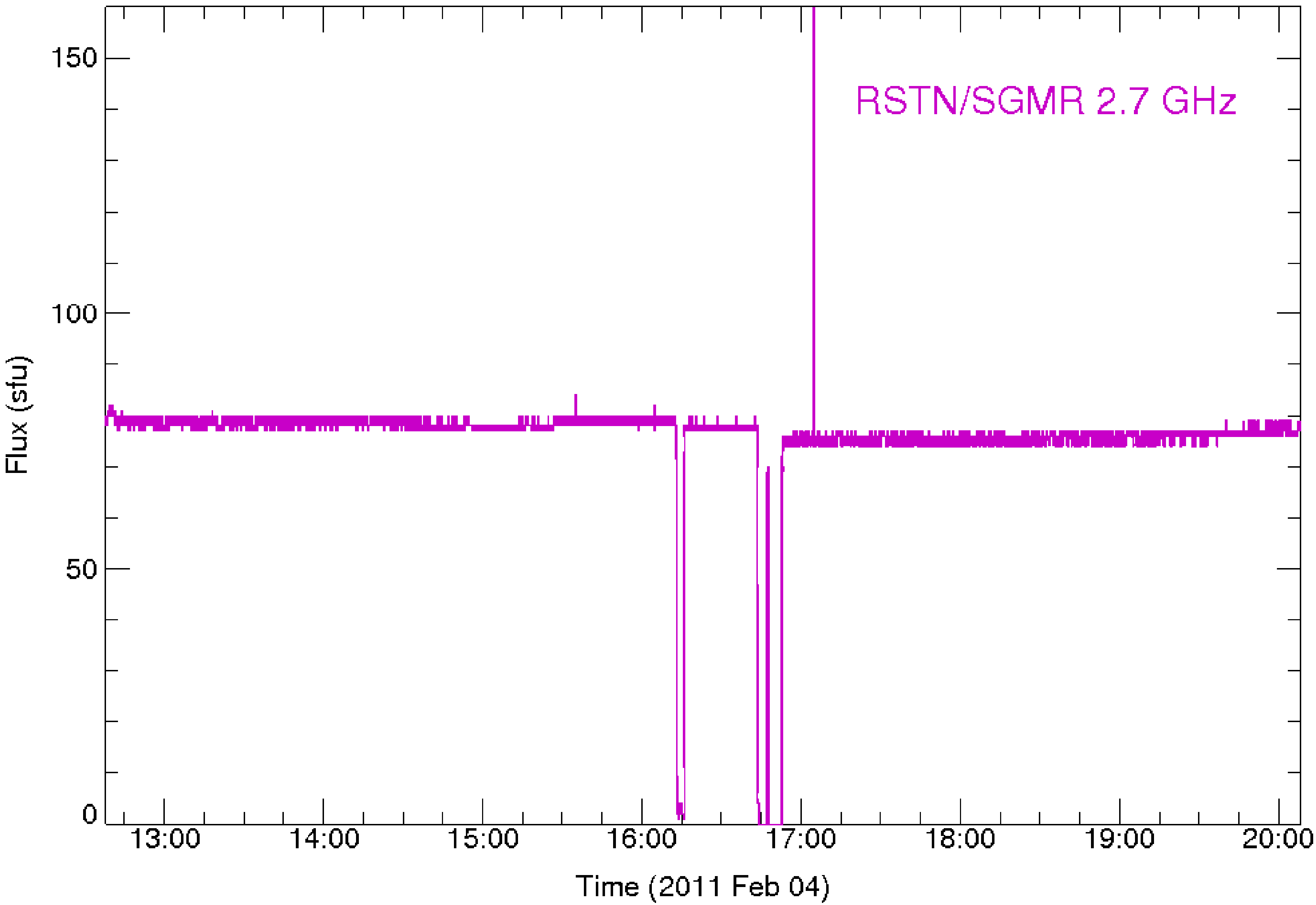
1973



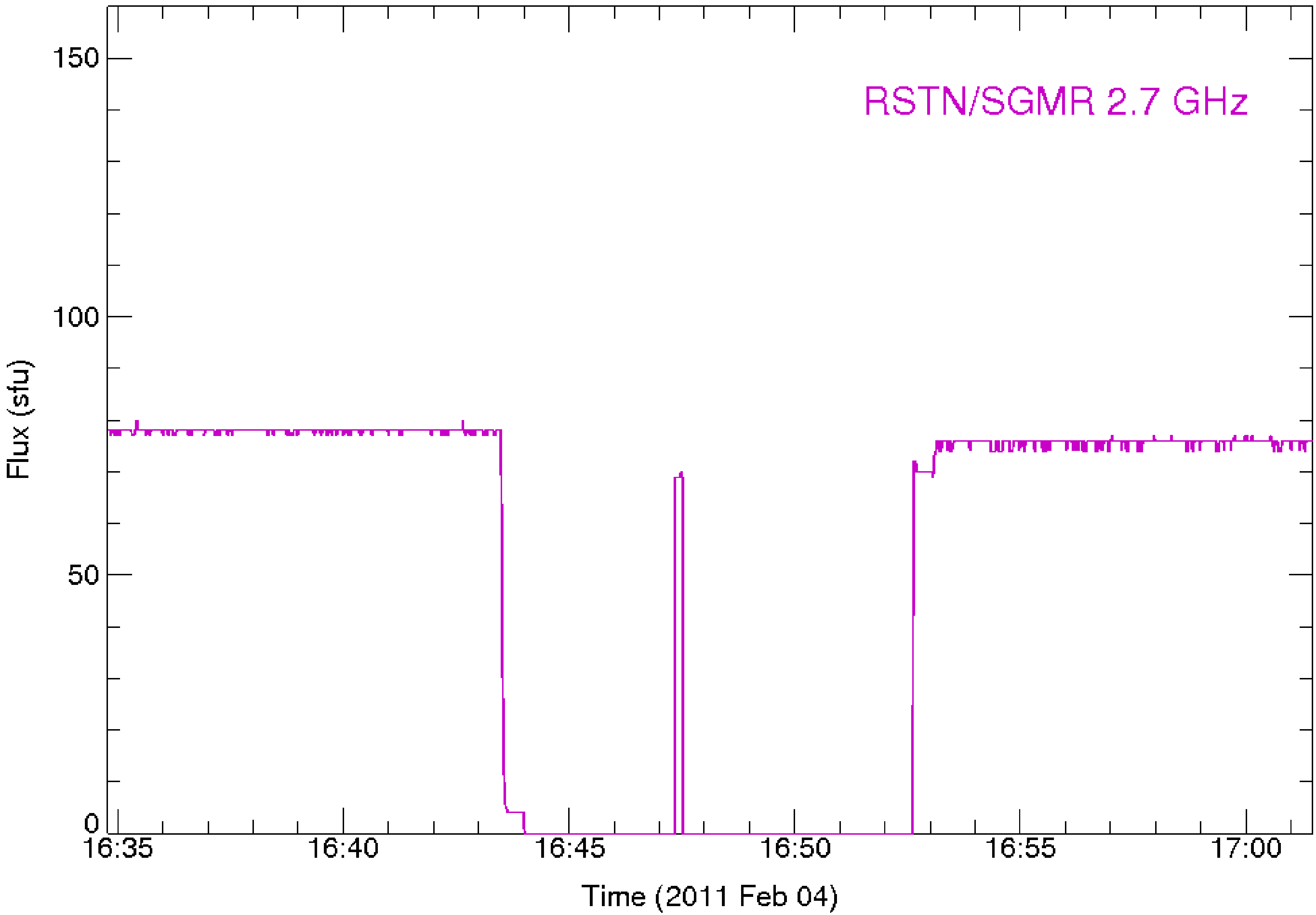
NoRP 2.0 GHz
Flux (sfu)
150
100
50
0
22:00
00:00
02:00
04:00
06:00
Time (2011 Sep 17/18)

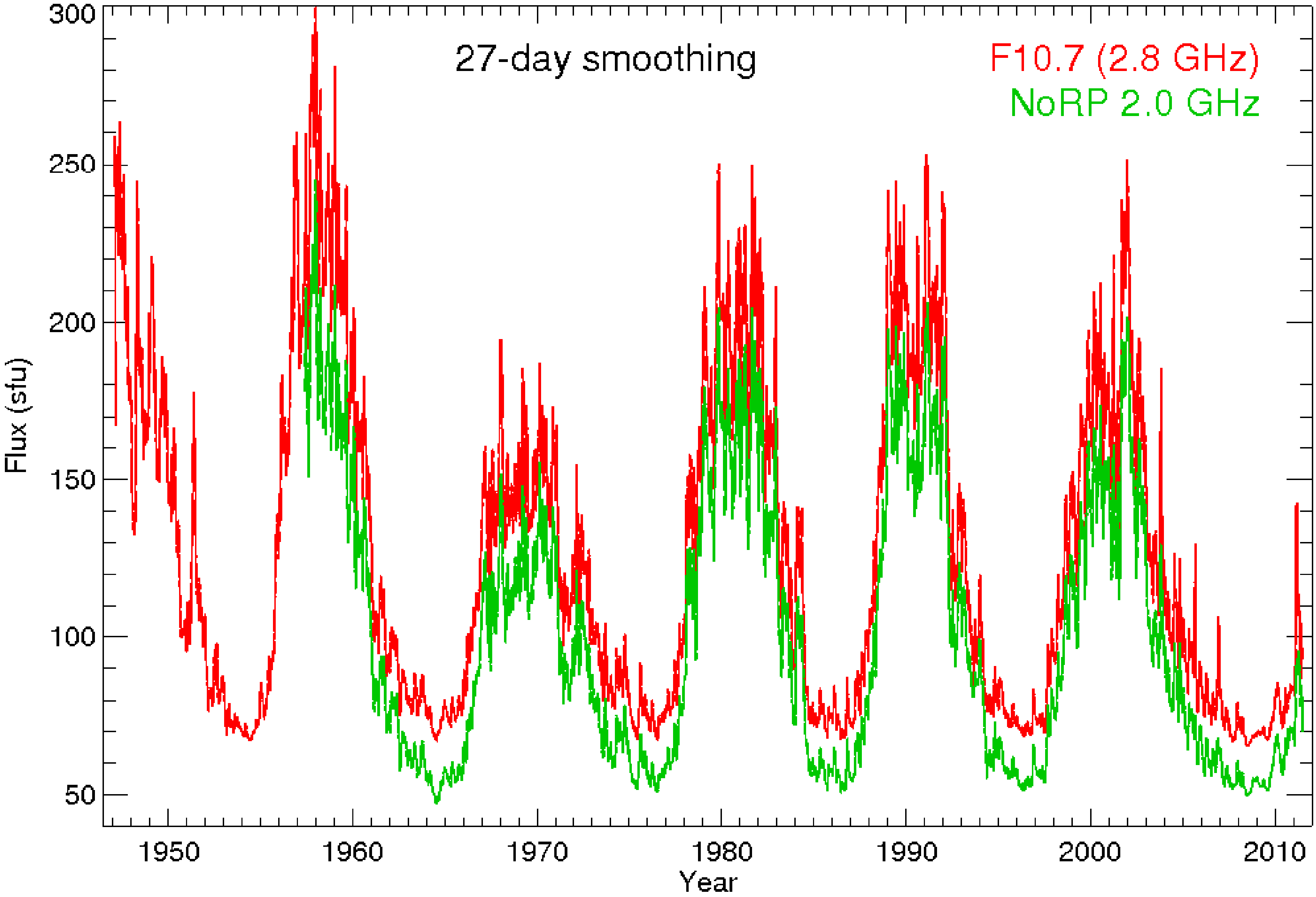


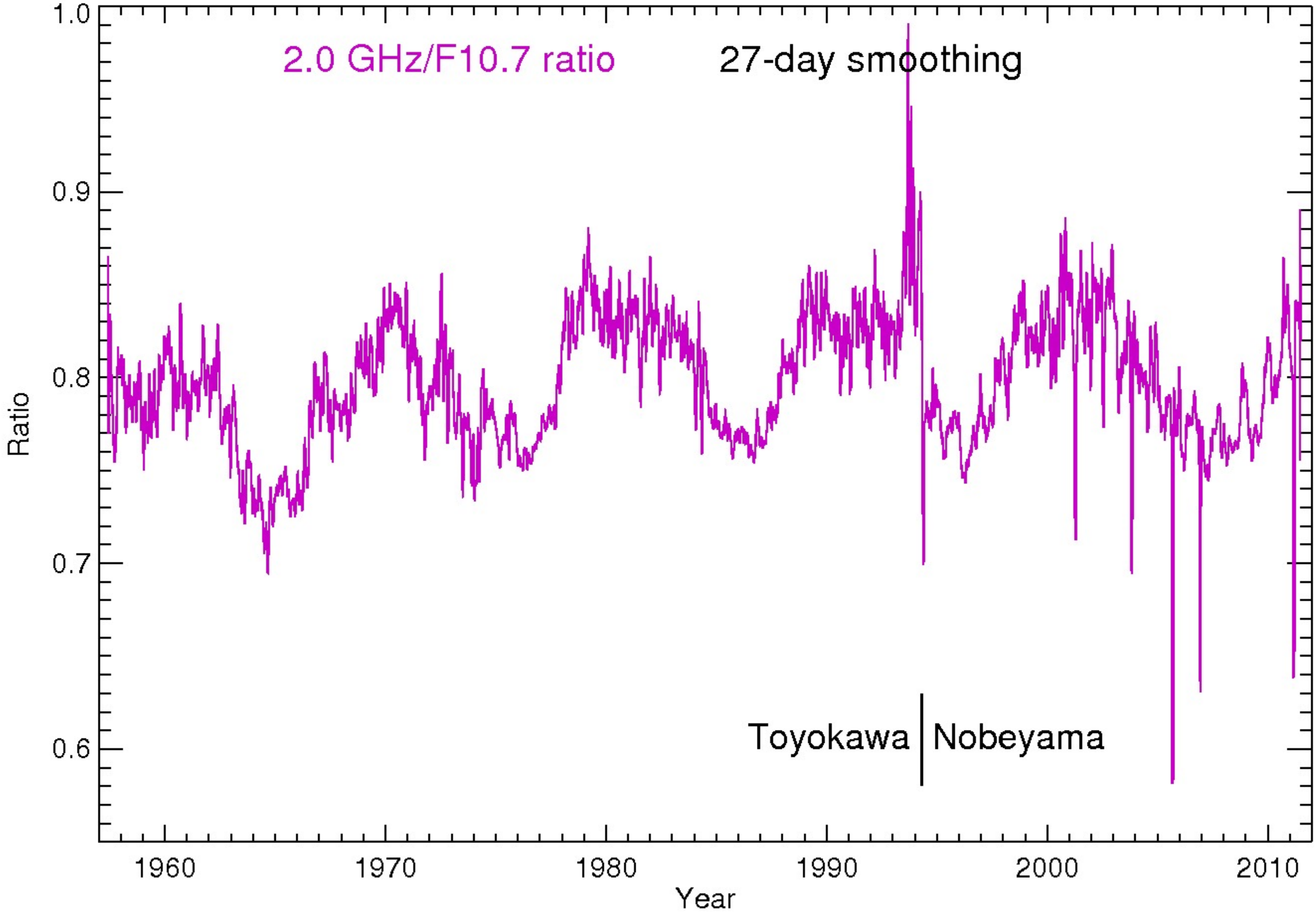
NoRP 2.0 GHz
150
100
50
0
Flux (sfu)
02:24
02:26
02:28
02:30
02:32
02:34
02:36
02:38
Time (2011 Sep 18)

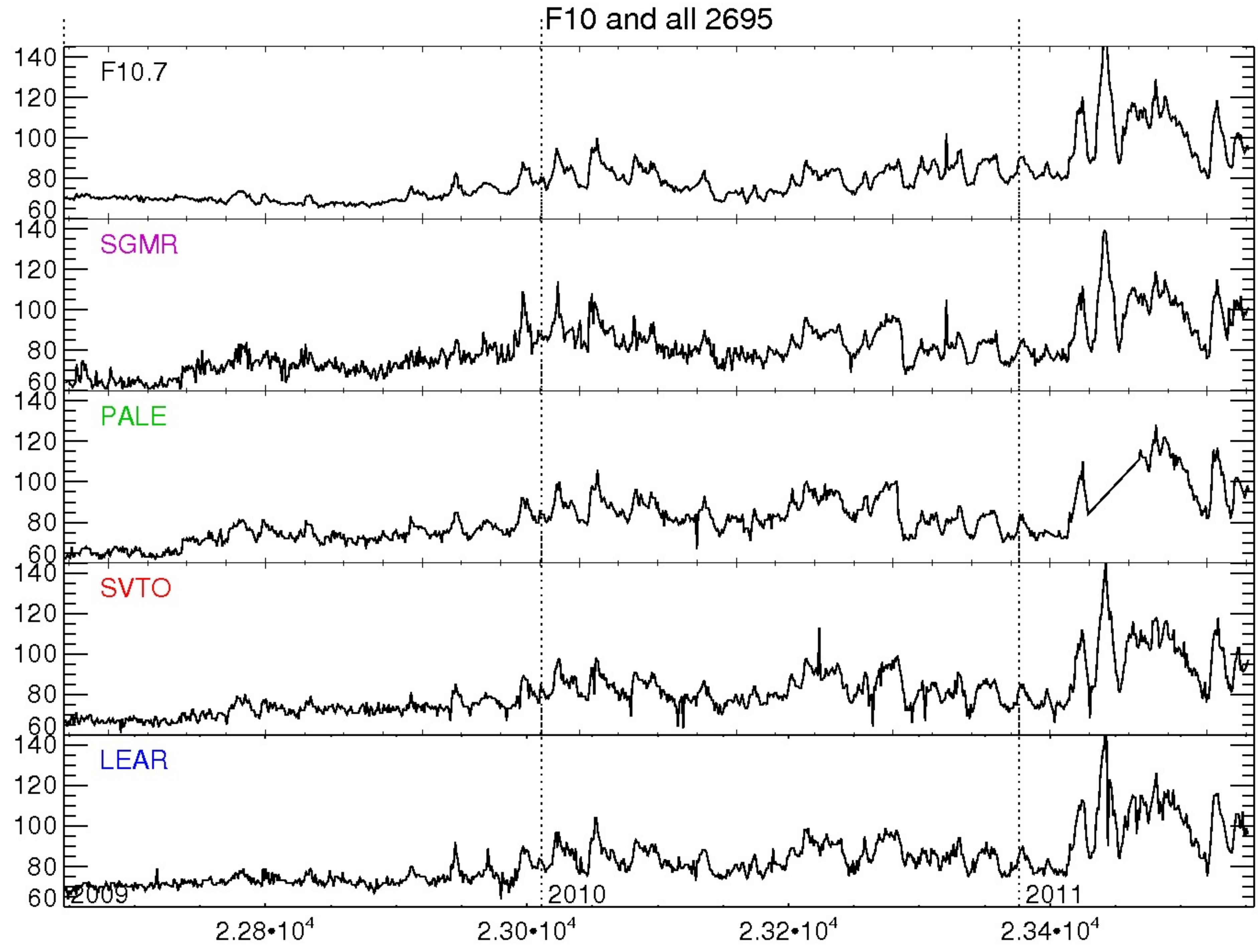


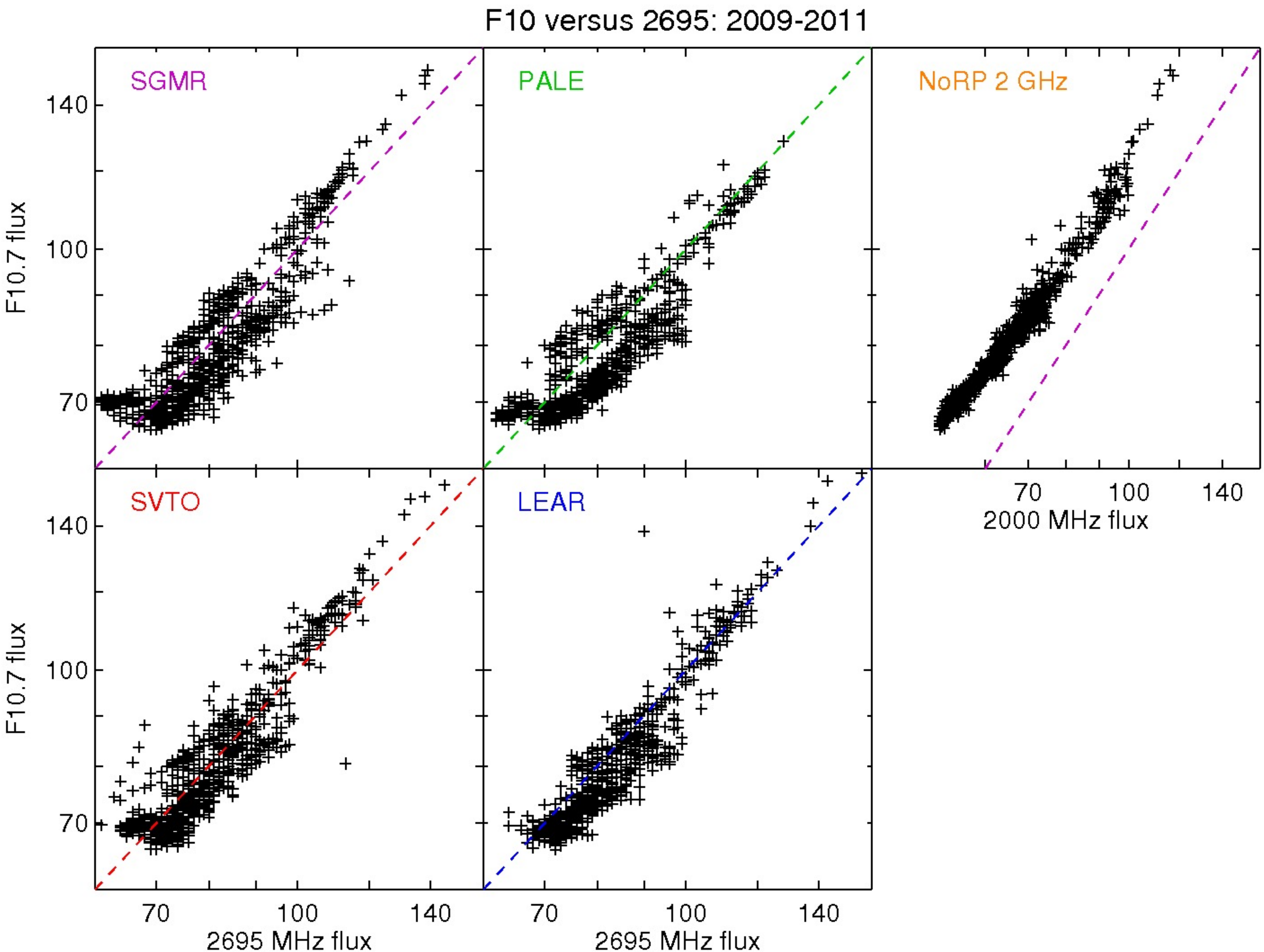
RSTN/SGMR 2.7 GHz
150
100
50
0
Flux (sfu)
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
Time (2011 Feb 04)


RSTN/SGMR 2.7 GHz
Flux (sfu)
150
100
50
0
16:35
16:40
16:45
16:50
16:55
17:00
Time (2011 Feb 04)


27-day smoothing
F10.7 (2.8 GHz)
NoRP 2.0 GHz
Flux (sfu)
Year
300
250
200
150
100
50
1950
1960
1970
1980
1990
2000
2010

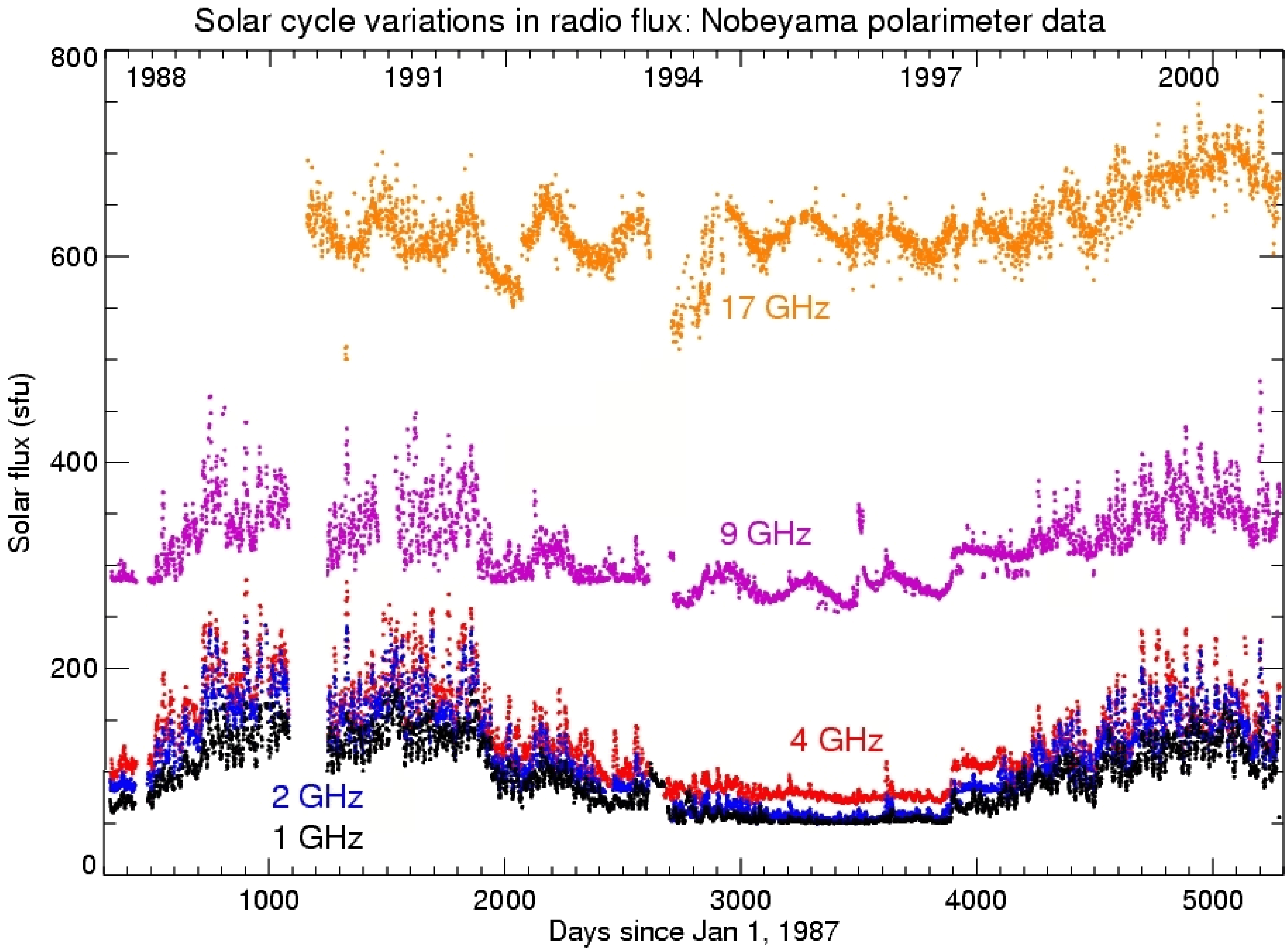

2.0 GHz/F10.7 ratio
27-day smoothing
Toyokawa
Nobeyama
Ratio
Year
1.0
0.9
0.8
0.7
0.6
1960
1970
1980
1990
2000
2010


F10 and all 2695
F10.7
SGMR
PALE
SVTO
LEAR
2009
2010
2011
140
120
100
80
60
2.28•10^4
2.30•10^4
2.32•10^4
2.34•10^4

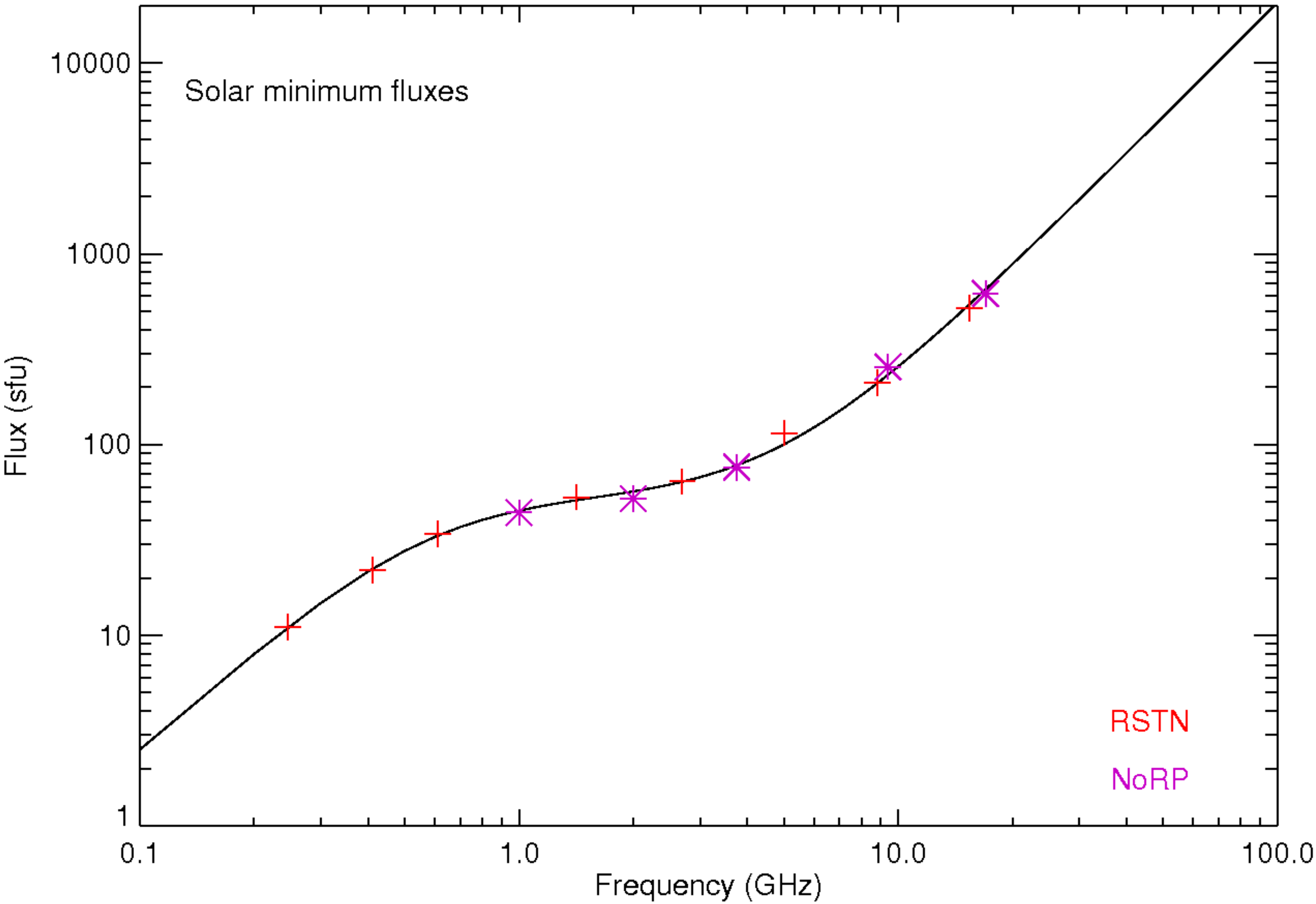


F10 versus 2695: 2009-2011
SGMR
PALE
NoRP 2 GHz
SVTO
LEAR
F10.7 flux
140
100
70
2695 MHz flux
2000 MHz flux

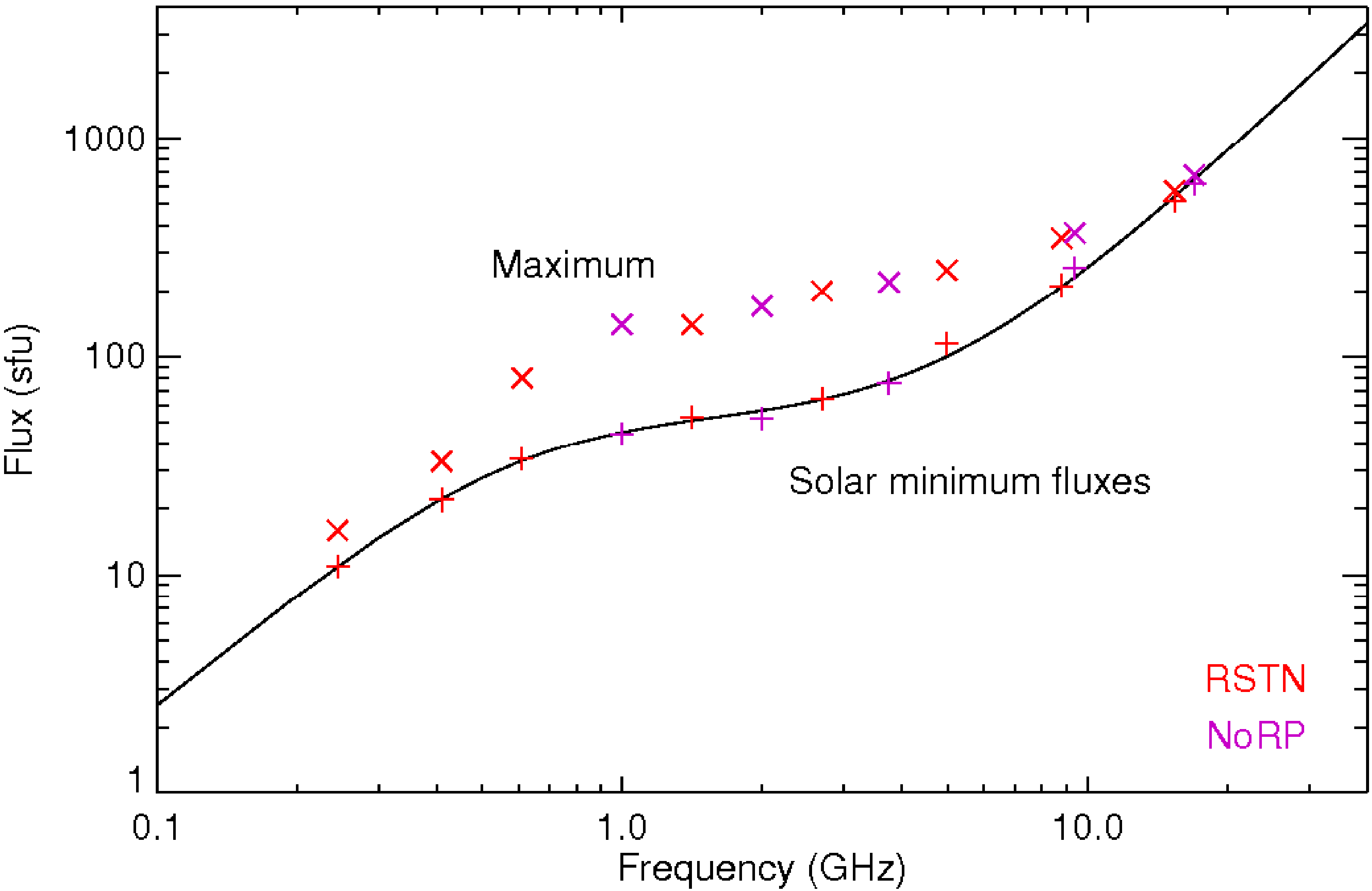
The Radio Sun Cycle



Solar minimum flux spectrum



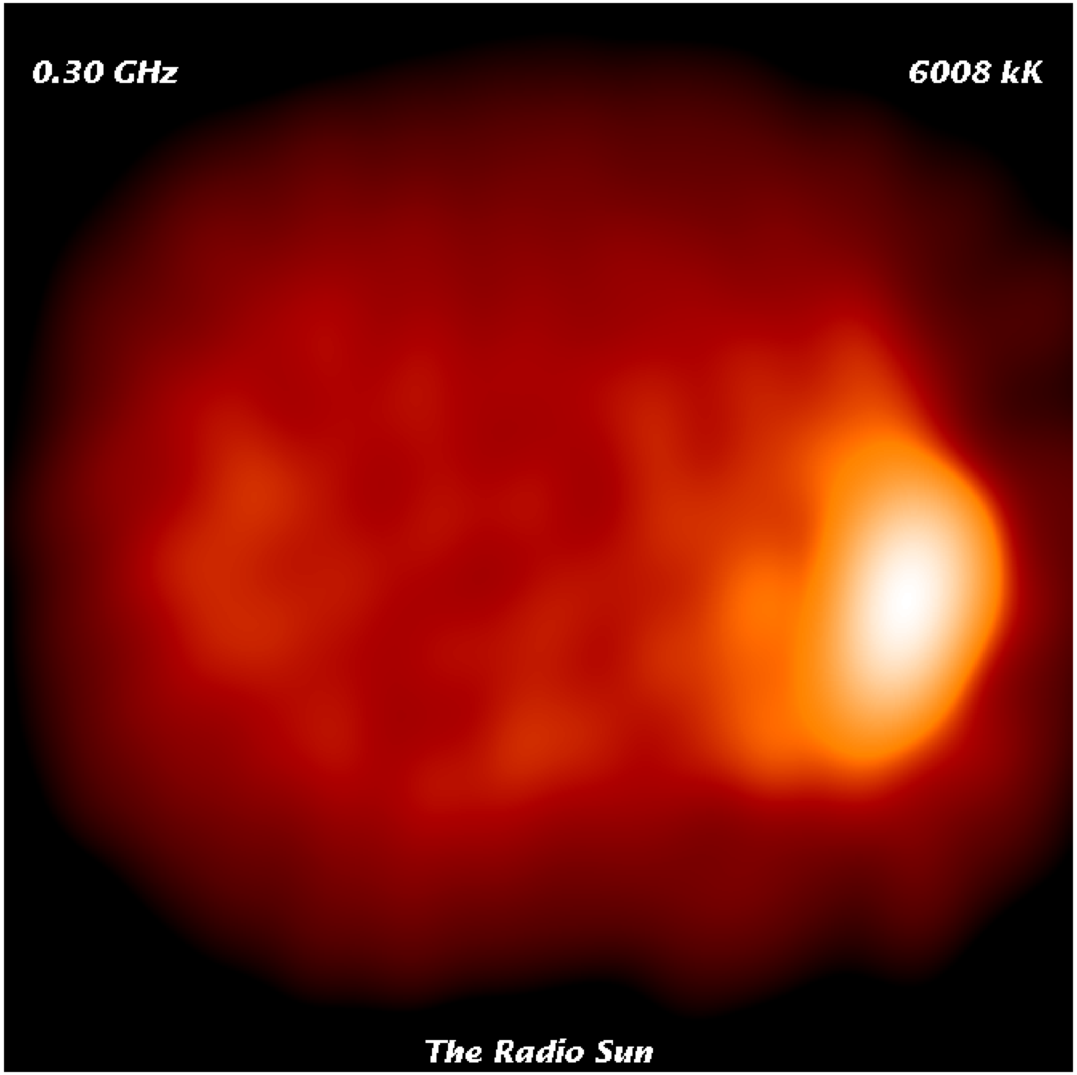
Solar maximum flux spectrum



Radio Emission Mechanisms

- **Bremsstrahlung** due to thermal plasma occurs throughout the solar atmosphere and is the dominant mechanism in most of the corona. It is optically thin above a few GHz and usually weakly polarized.
- **Gyroresonance emission** (emission from nonrelativistic thermal plasma at low harmonics of the electron gyrofrequency 2.8 B MHz) is strong wherever B > 300 G in the corona and produces optically thick emission in active regions which may be highly polarized.
- Bremsstrahlung in the corona is optically thick above active regions below 2 GHz, optically thin above 4 GHz (**flat flux spectrum**).
- Gyroresonance emission can be optically thick up to 20 GHz but area decreases as frequency increases (**flux $\propto$ f^2Area**)

The Radio Sun in Frequency



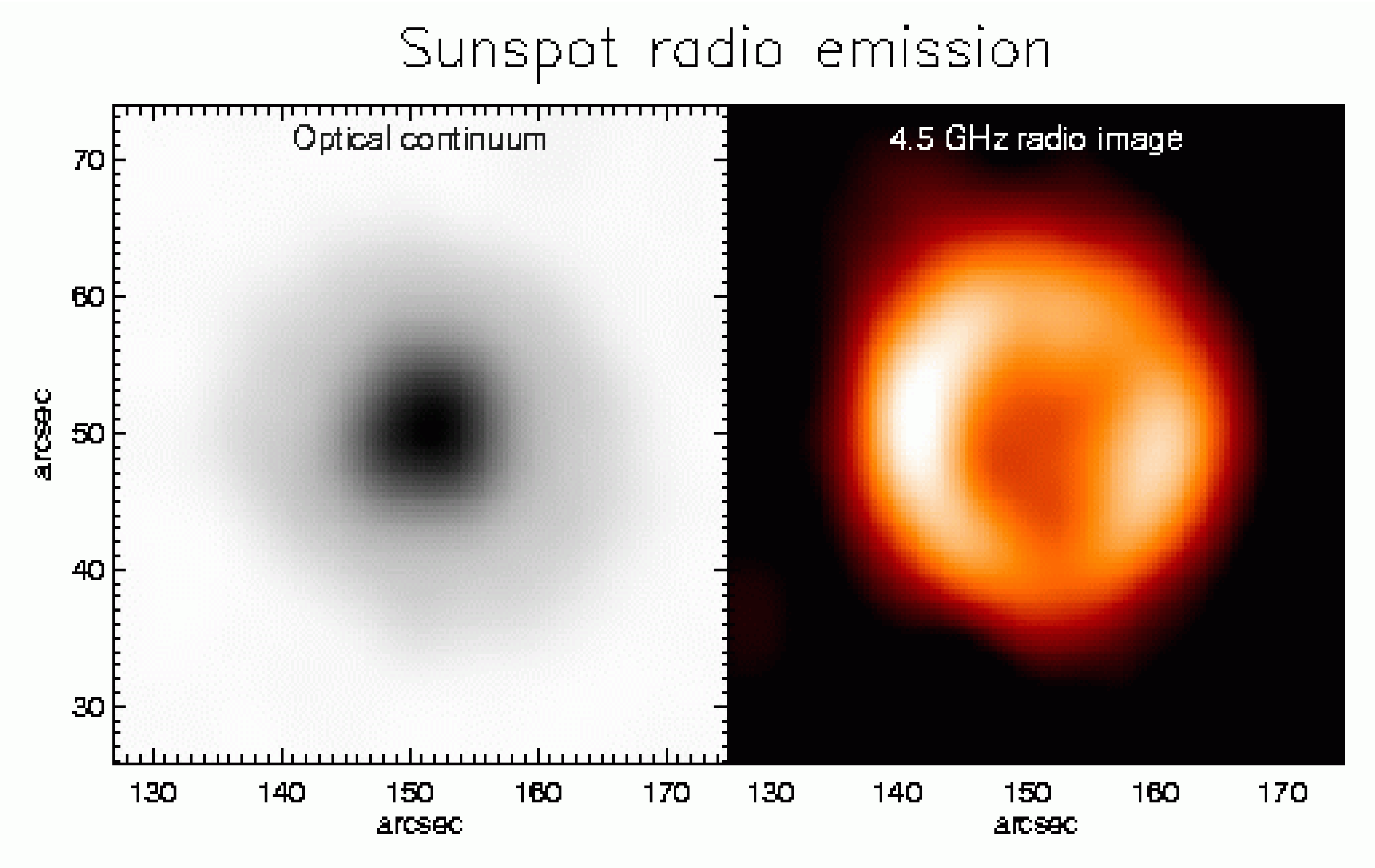
Solar radio disk temperatures

Solar minimum disk brightness temperatures:

600000 K at 0.3 GHz	- optically thick corona
190000 K at 1 GHz	- optically thin corona
35000 K at 2.8 GHz	- upper chromosphere
25000 K at 3.8 GHz	- upper chromosphere
17000 K at 9.4 GHz	- upper chromosphere
10000 K at 17 GHz	- chromosphere
7000 K at 86 GHz	- chromosphere

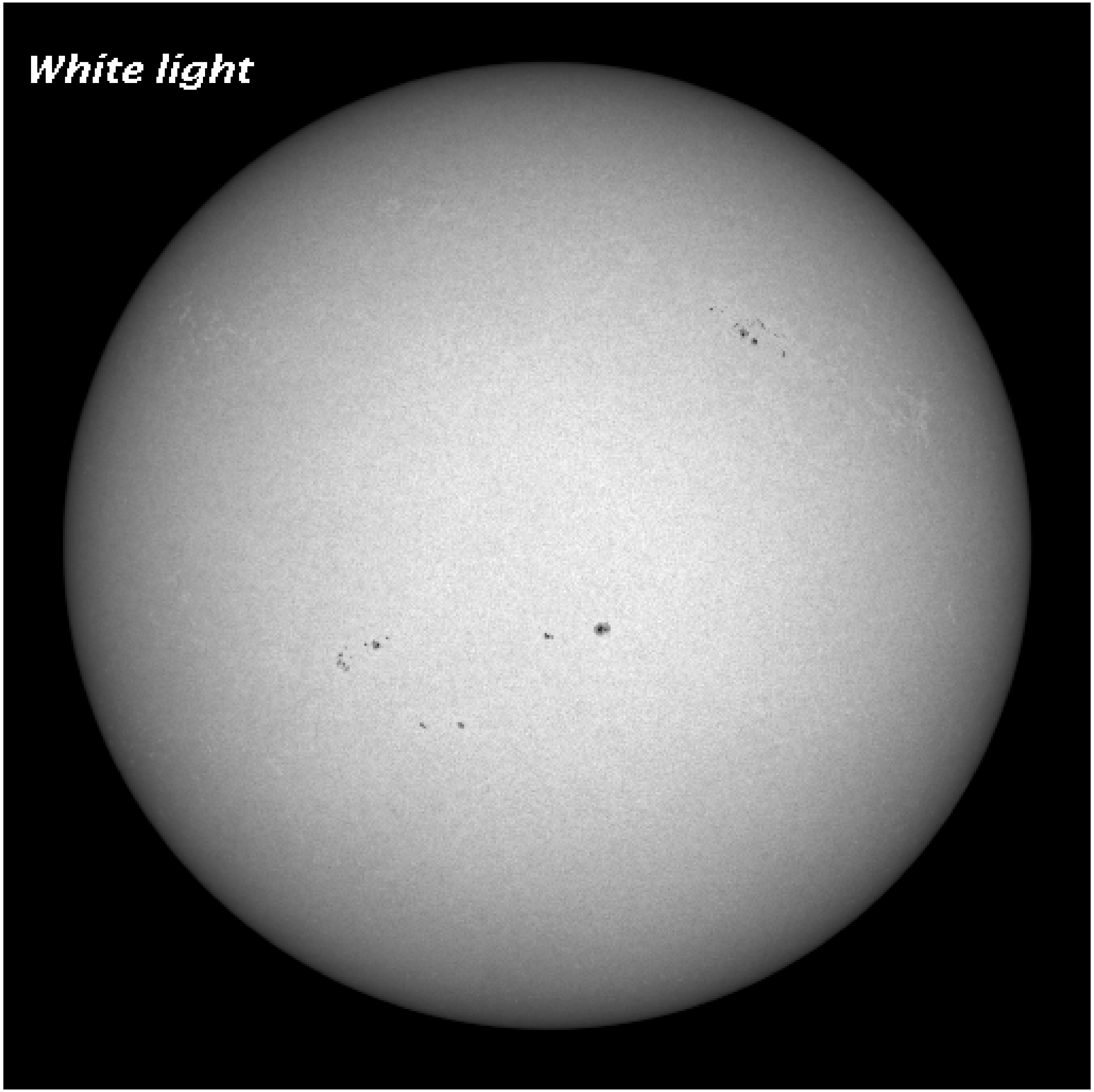
Solar radio flux = disk area x T x $(\text{frequency})^2$

Radio Emission from Magnetic Fields

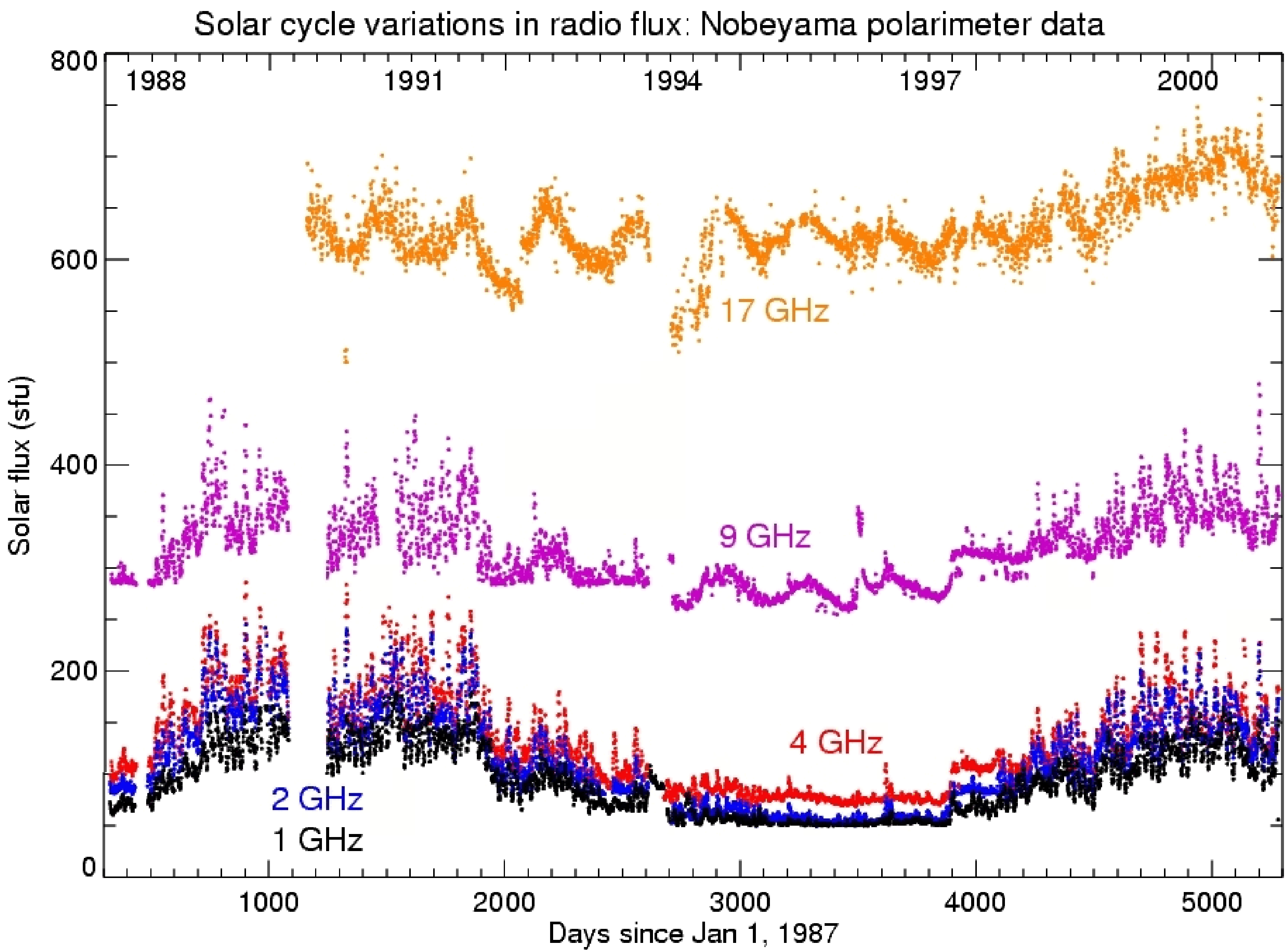


Radio emission from a simple round sunspot

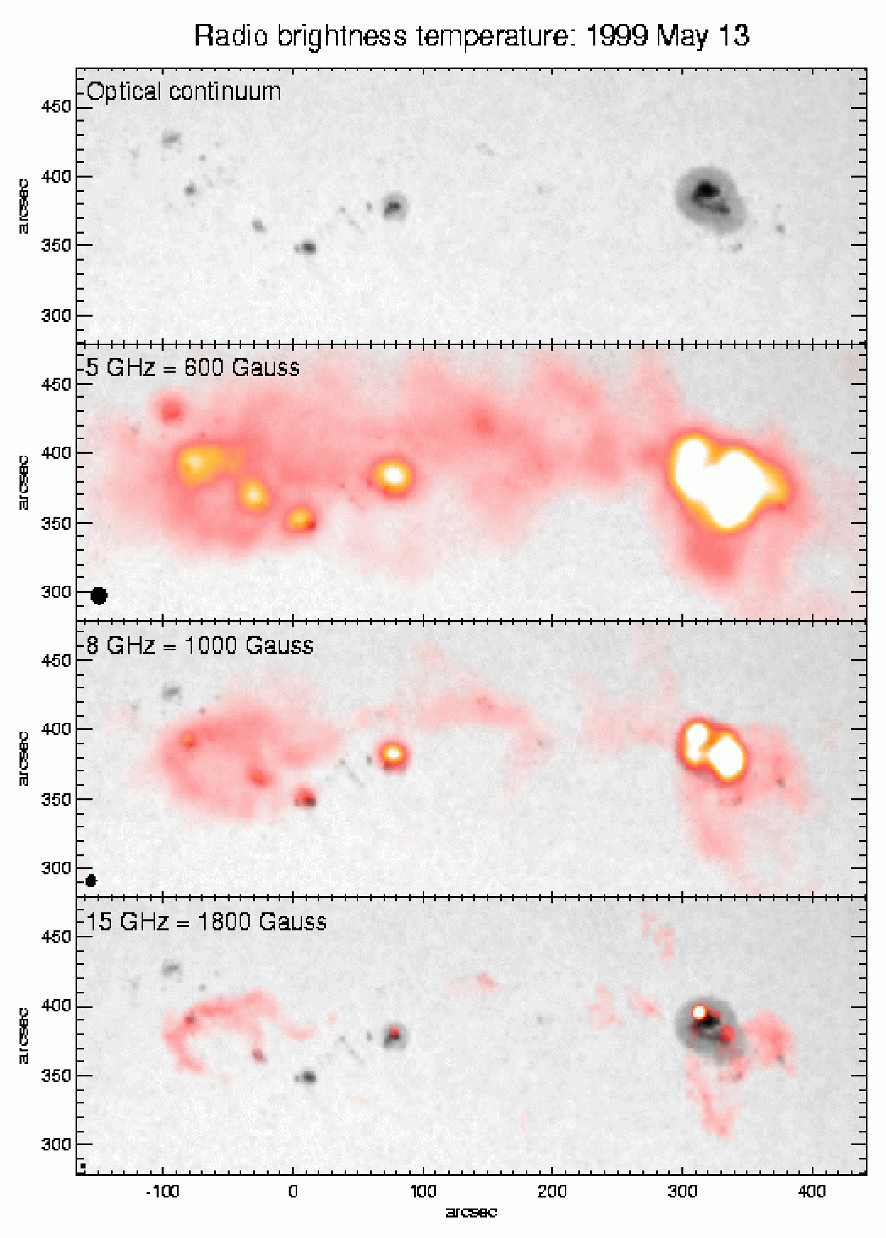
The Radio Sun cf EUV and Optical Images

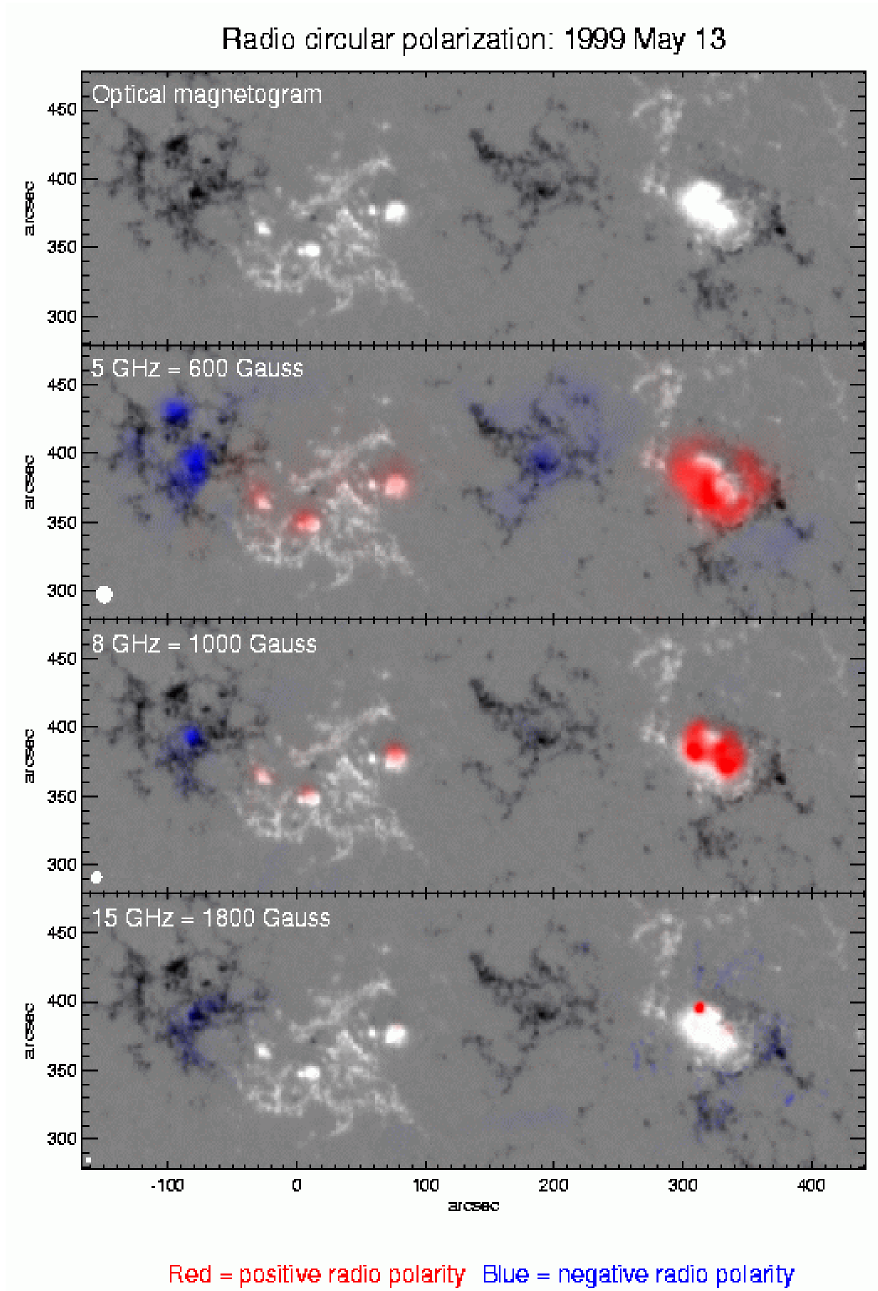


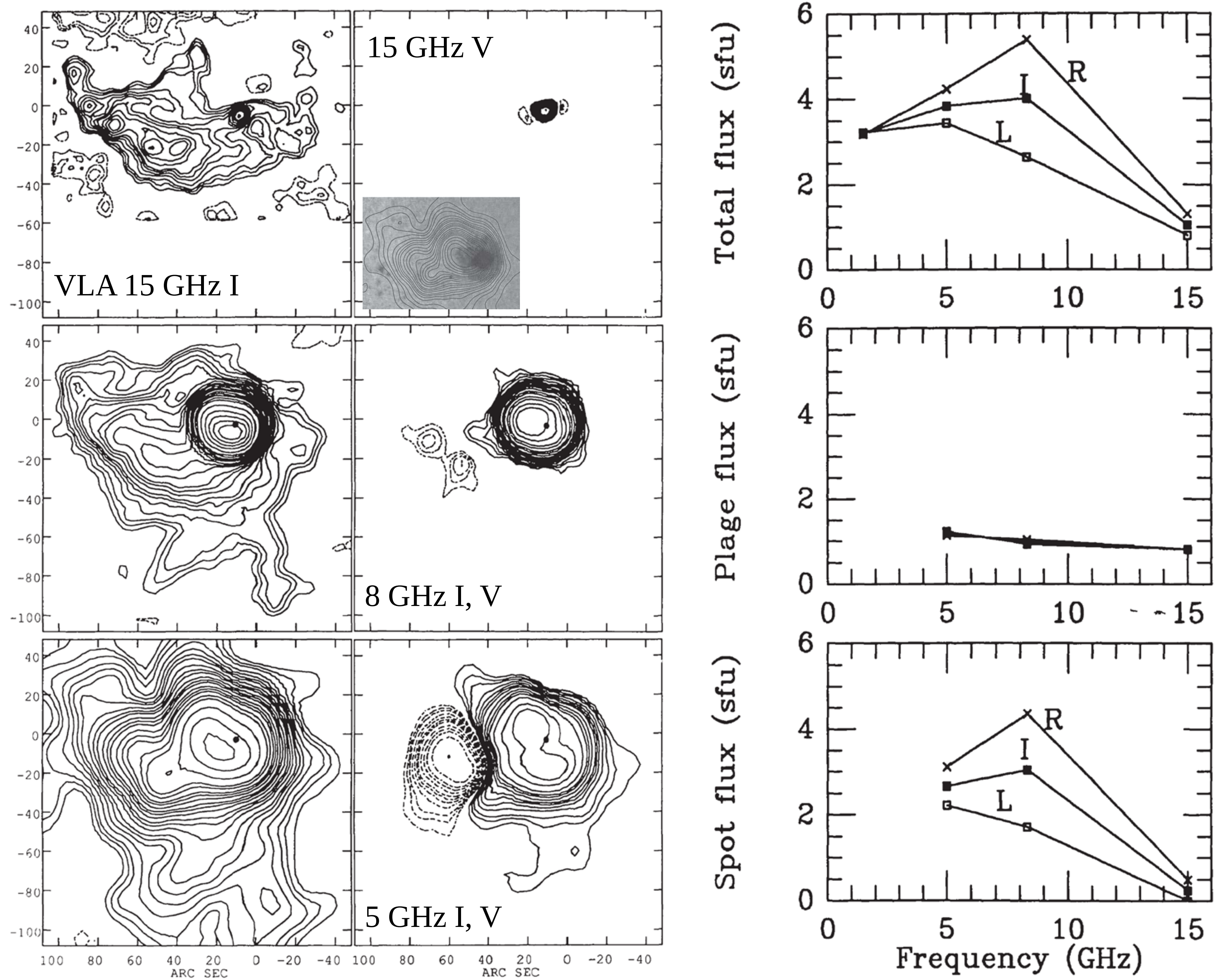
The Radio Sun Cycle



Radio Emission from the Solar Corona

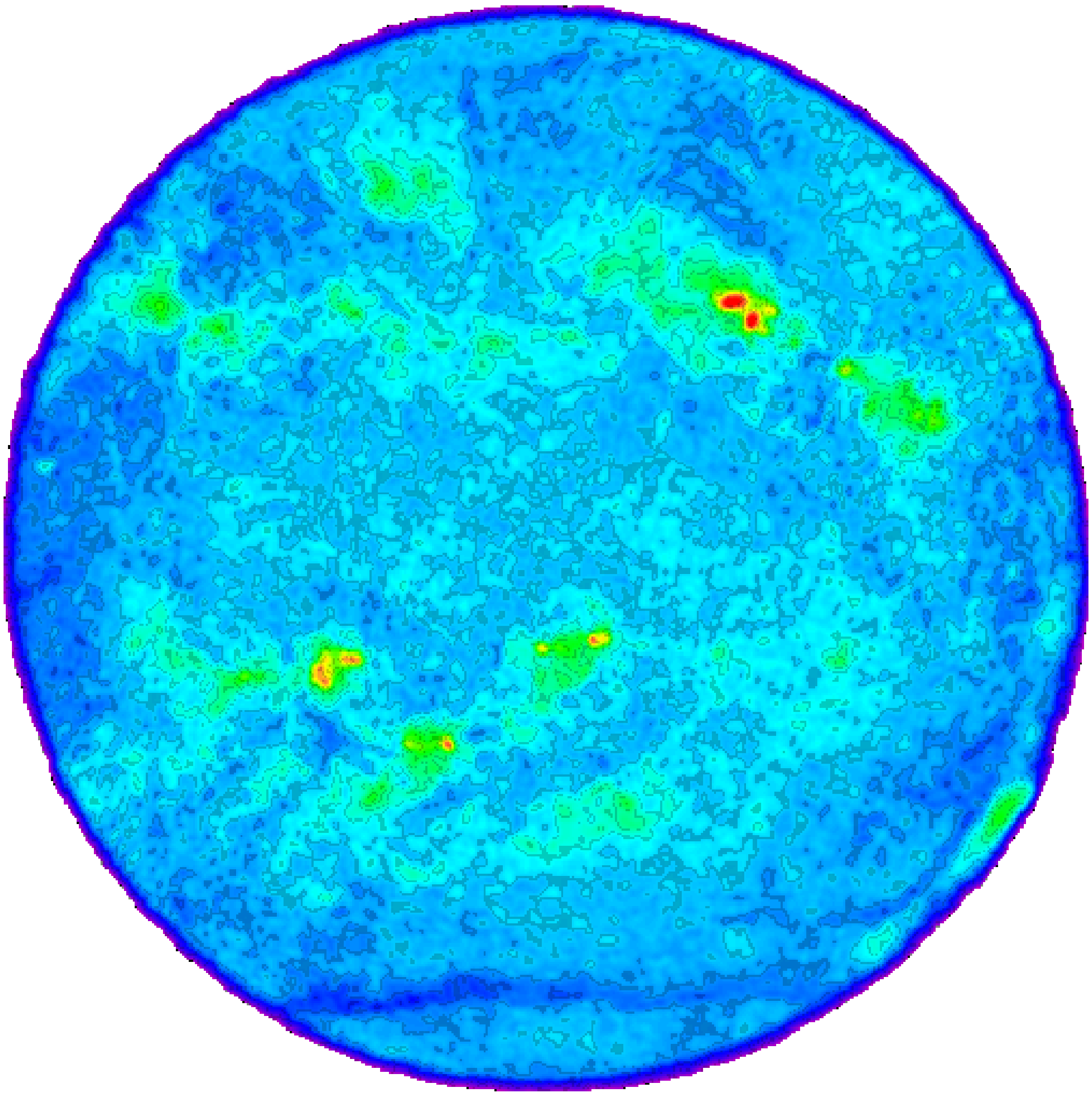






VLA 15 GHz I
15 GHz V
8 GHz I, V
5 GHz I, V
ARC SEC
ARC SEC
Total flux (sfu)
Plage flux (sfu)
Spot flux (sfu)
Frequency (GHz)
R
I
L

The Radio Sun at 4.6 GHz



What produces F10.7?

Three contributions:

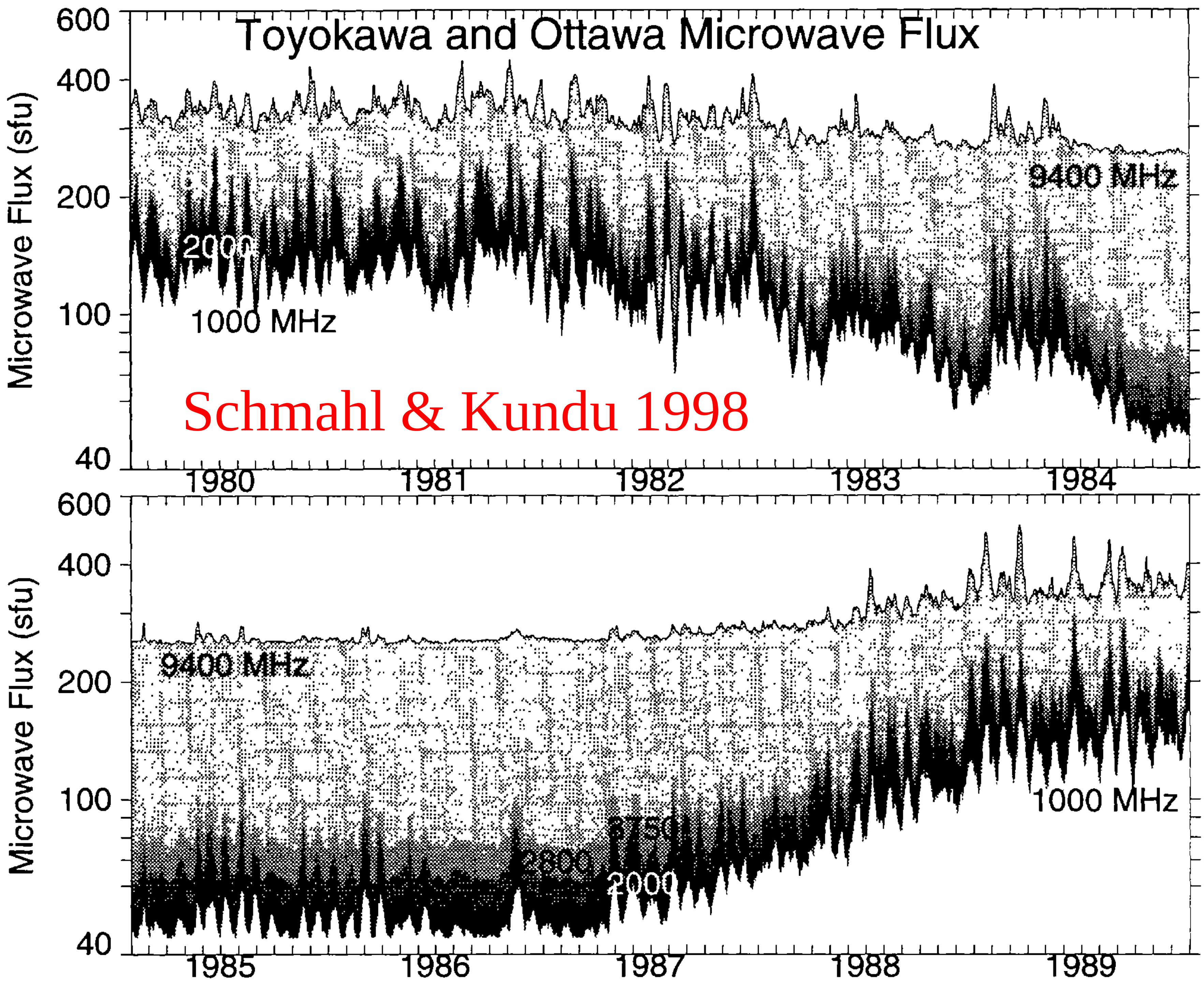
- Chromospheric emission from disk
- Thermal bremsstrahlung from the corona (optically thick or thin?)
- Coronal gyroresonance emission from active regions

Controversy over relative contributions to variable component:

- dominated by thermal bremsstrahlung? (Tapping et al)
- dominated by gyroresonance emission? (Schmahl & Kundu)

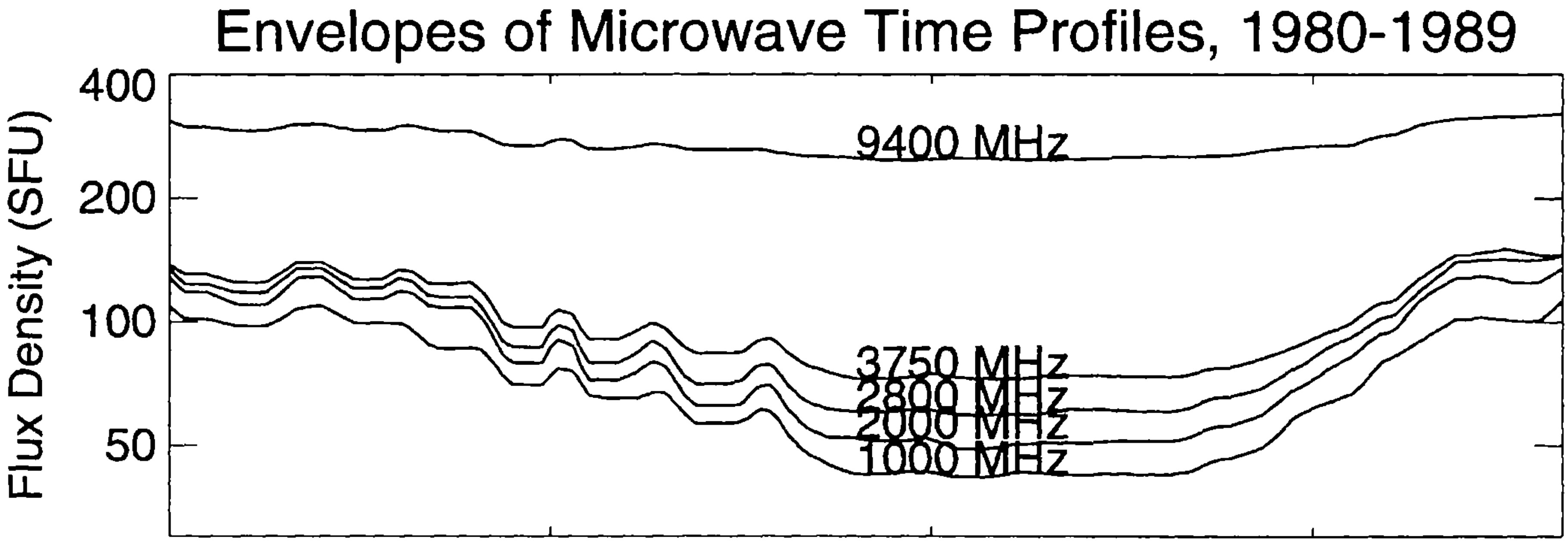
No imaging at F10.7 till now, hence the controversy.

In active regions bremsstrahlung related to magnetic field.



Schmahl & Kundu 1998

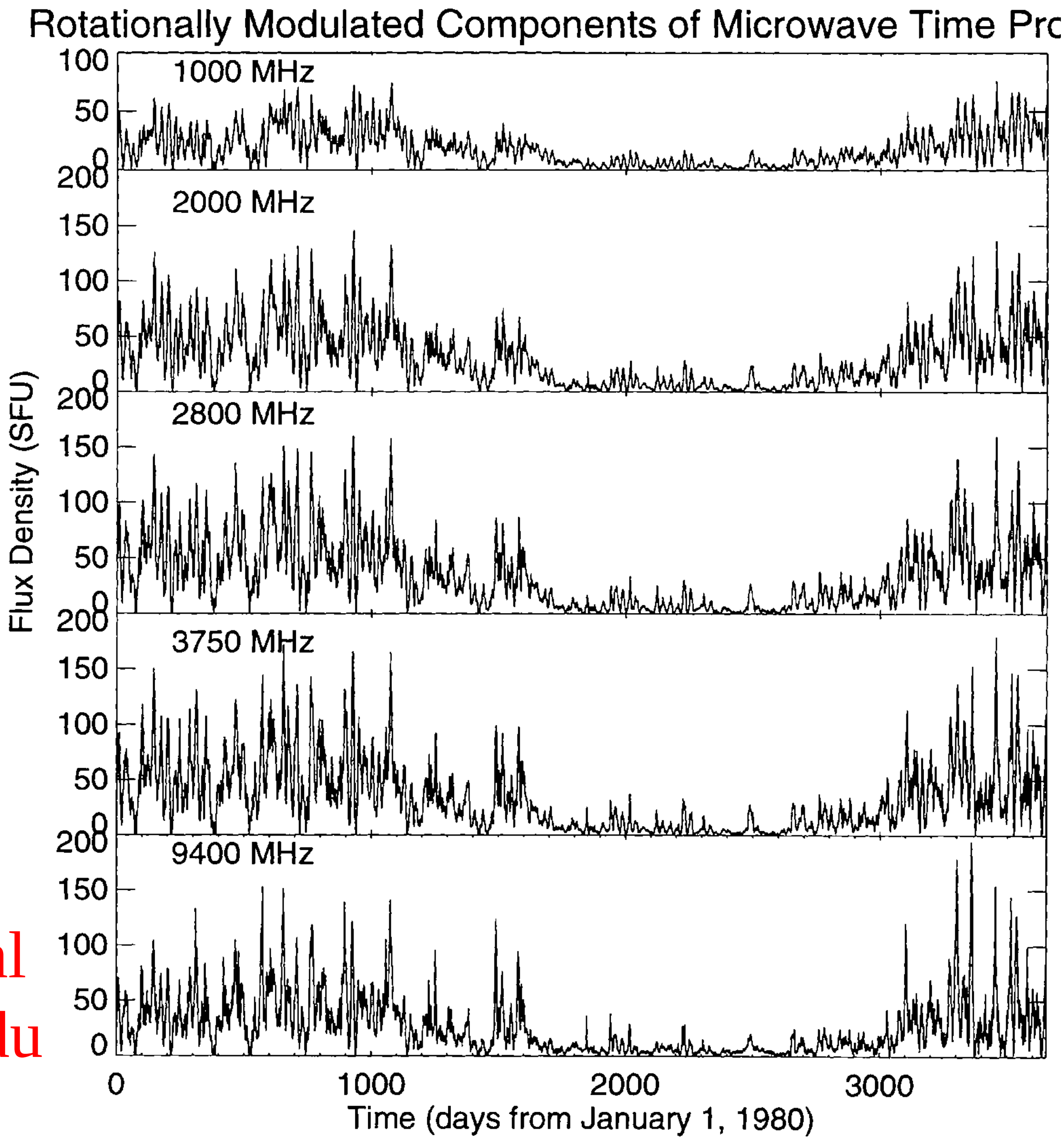
Fit rotationally modulated component



"Lower envelope" generated by taking minimum on 155 day period and boxcar-smoothing over 81 days (Schmahl & Kundu 1998)

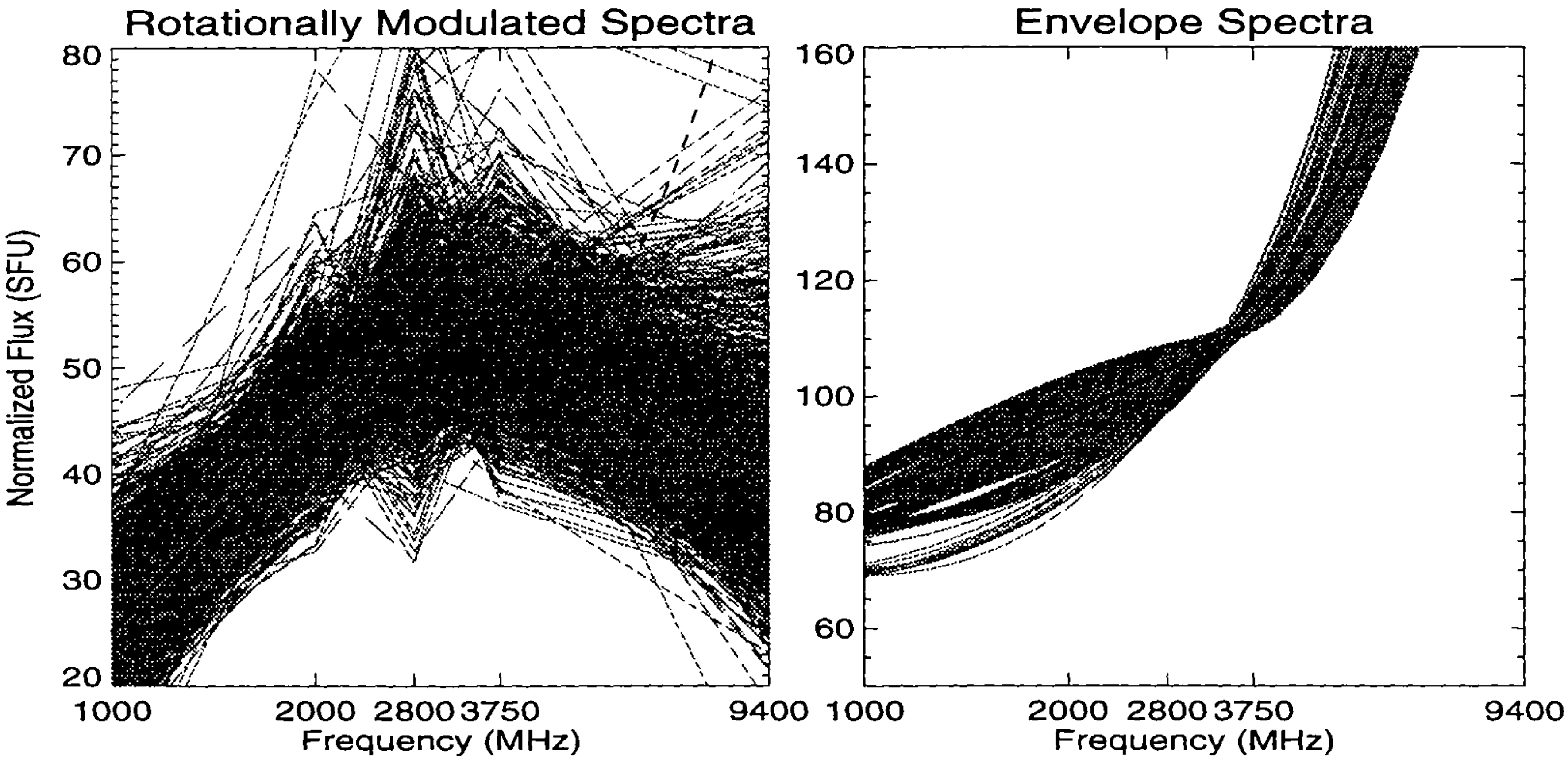
Table 1. The percentage of the total flux that is rotationally modulated for the years 1980-1989.

ν	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
1000	18.3	21.1	29.1	21.3	19.8	10.4	9.5	14.5	18.9	23.2
2000	27.3	28.6	35.5	26.3	22.9	11.7	9.8	15.4	24.1	27.7
2800	28.8	29.9	35.8	25.0	21.9	10.1	8.5	14.1	23.9	26.0
3750	27.4	28.5	33.5	21.9	19.6	9.0	7.1	11.7	22.7	25.1
9400	11.2	12.5	14.4	7.0	6.5	2.6	2.4	3.3	8.1	11.4



Schmahl & Kundu 1998

Comparison of spectra of modulated and unmodulated components



Spectrum of modulated component has a peak at microwave frequencies, the envelope component is closer to the solar minimum shape (but is not the same)

Schmahl & Kundu 1998

Future Radio Monitoring

- Ken discussed developments for F10.7 (new station for RBO)
- Imaging of F10 with EVLA and ATA: big study planned
- USAF will upgrade RSTN system in about 4-5 years: more frequencies, need to pay attention to calibration
- Concerned about the future of the Nobeyama (previously Toyokawa) Polarimeters: Nobeyama Radioheliograph will cease operations in a few years. Very valuable independent check at microwave frequencies.
- What repeatibility do we need? 1%? 5% 10%=USAF?
- Proposed Frequency Agile Radio Telescope, like Nobeyama Radioheliograph, designed for imaging not 1% calibration: may get to 5% across a wide range.

Temperature (solid) and density (dashed) as a function of height in the Sun's atmosphere