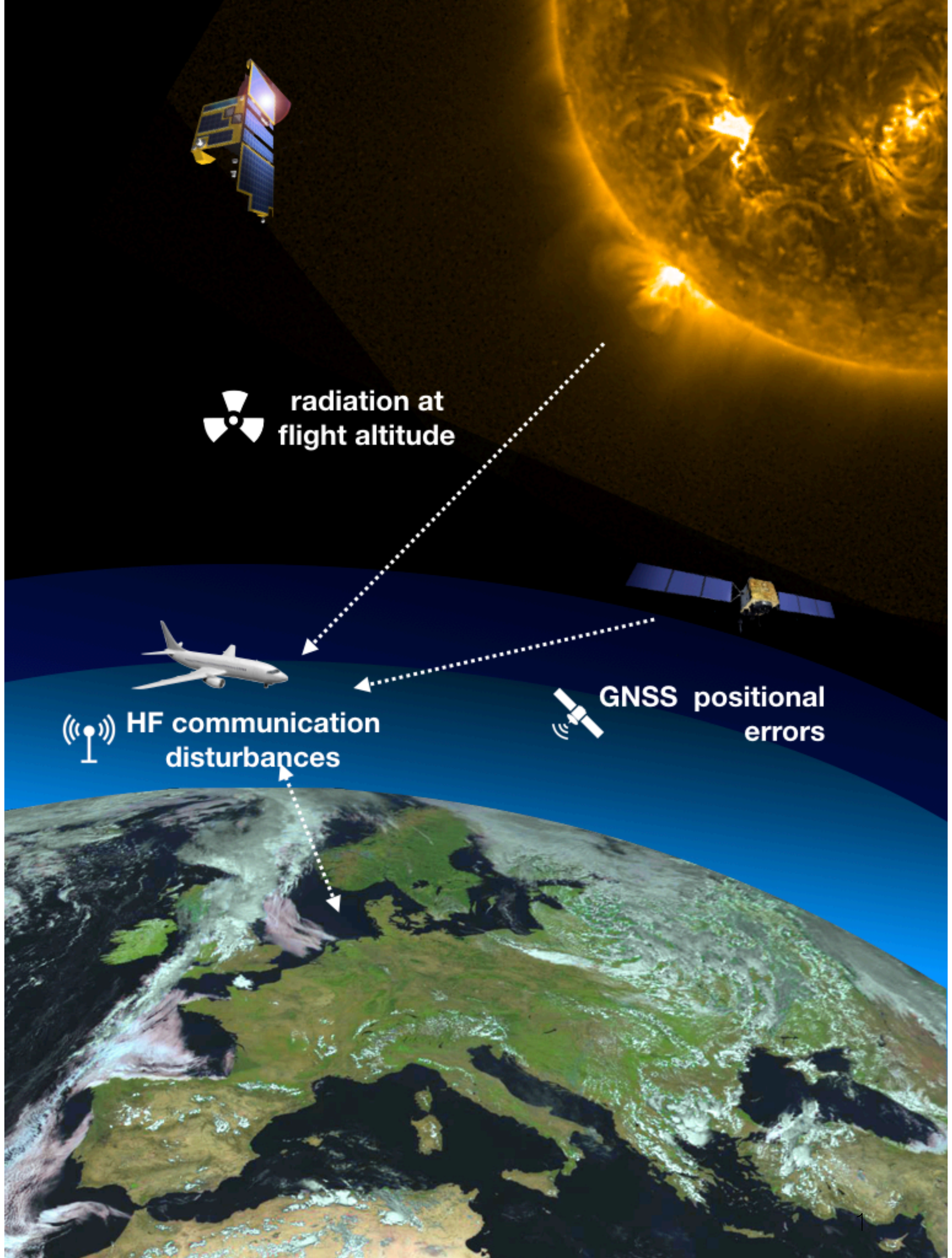


Space Weather impacts on Aviation

PECASUS advisories for ICAO

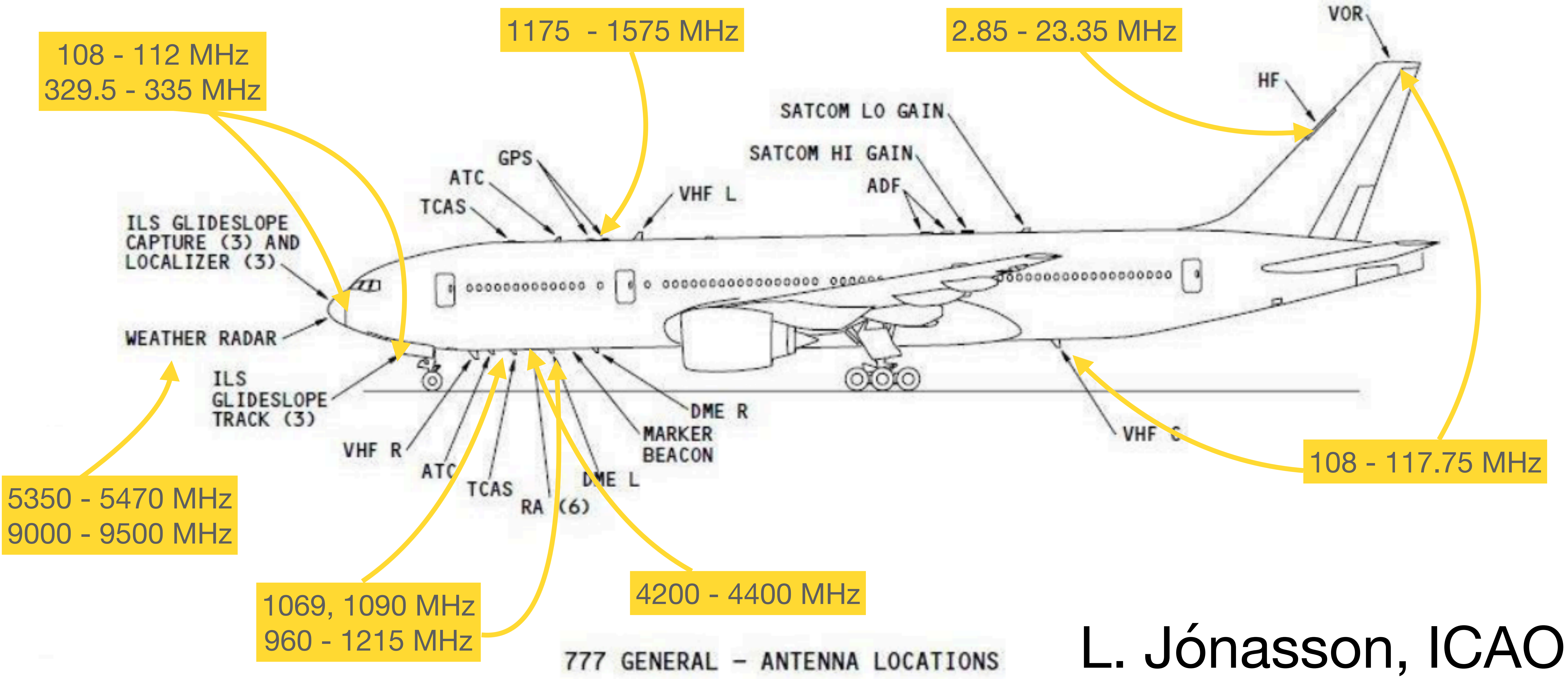
Impact of Solar Radio Burst on aviation
Christophe Marqué

Course by the
Solar-Terrestrial Centre of Excellence

March 2024

Aeronautical Frequency Spectrum Management

Accurate navigation, landing guidance, situational awareness
(airborne collision avoidance system, radar, radio altimeters)
weather radar and reliable communications with air traffic control



108 - 112 MHz
329.5 - 335 MHz

1175 - 1575 MHz

2.85 - 23.35 MHz

108 - 117.75 MHz

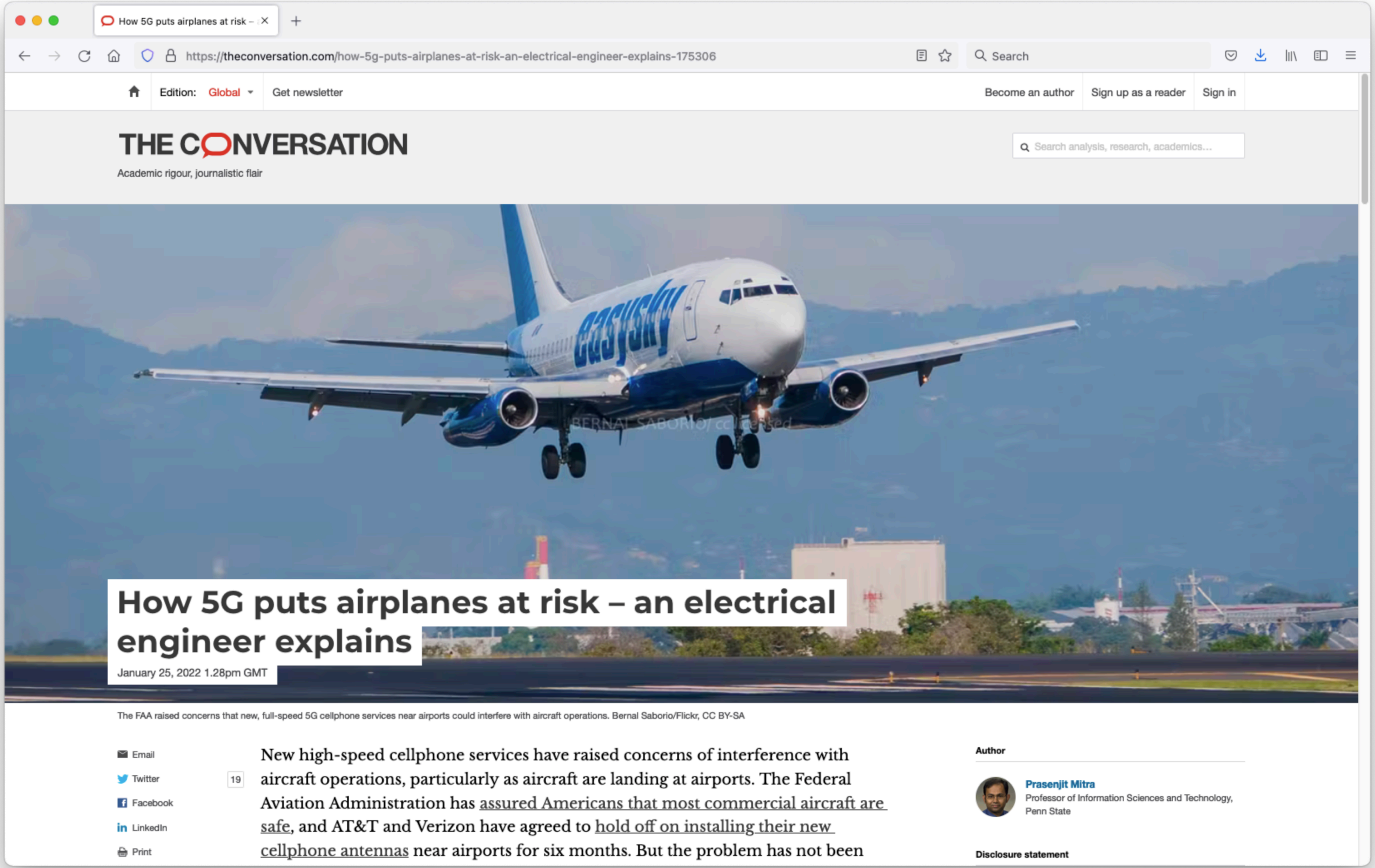
5350 - 5470 MHz
9000 - 9500 MHz

1069, 1090 MHz
960 - 1215 MHz

4200 - 4400 MHz

777 GENERAL – ANTENNA LOCATIONS

L. Jónasson, ICAO



How 5G puts airplanes at risk – an electrical engineer explains

January 25, 2022 1.28pm GMT

The FAA raised concerns that new, full-speed 5G cellphone services near airports could interfere with aircraft operations. Bernal Saborio/Flickr, CC BY-SA

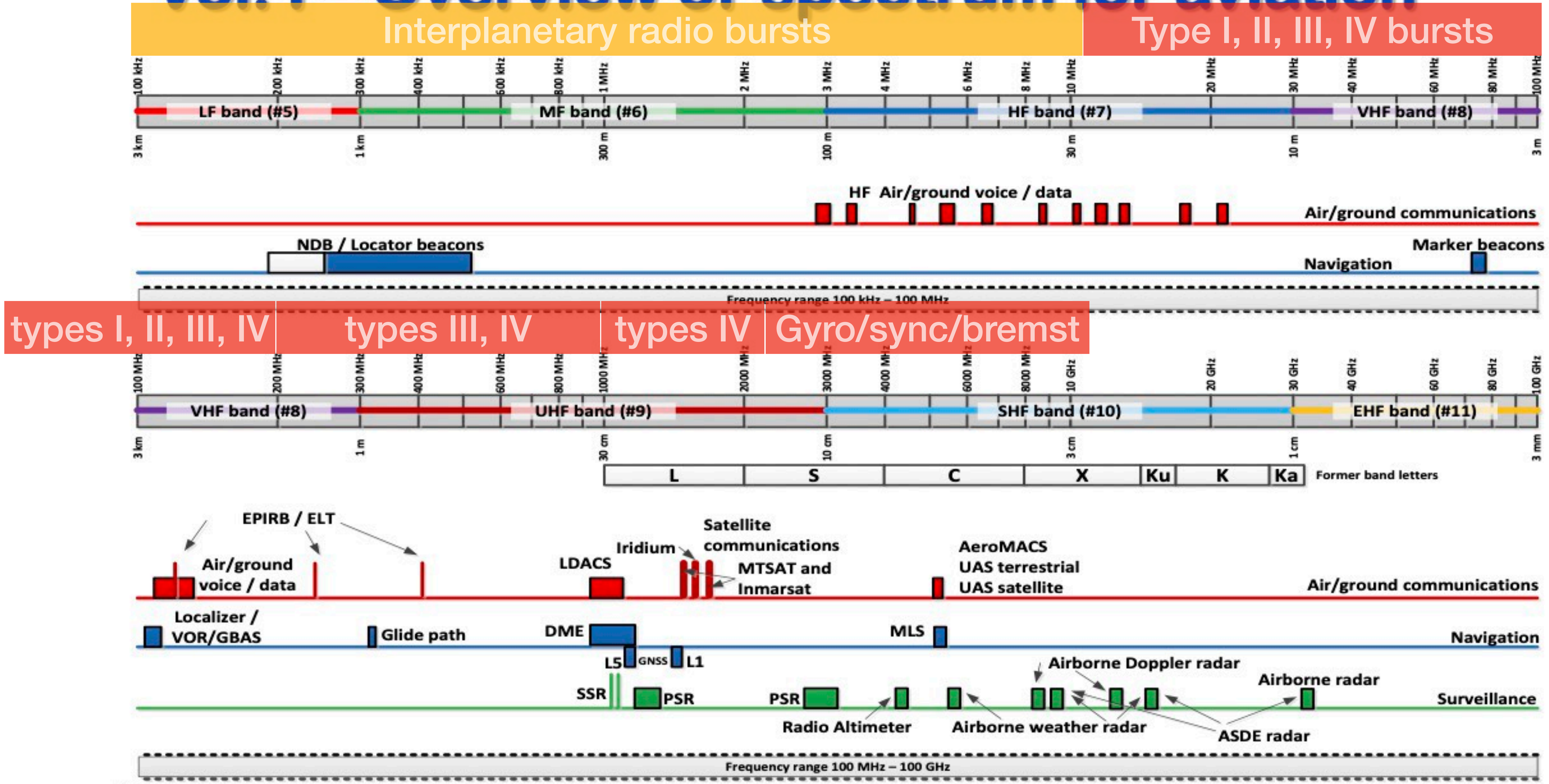
New high-speed cellphone services have raised concerns of interference with aircraft operations, particularly as aircraft are landing at airports. The Federal Aviation Administration has assured Americans that most commercial aircraft are safe, and AT&T and Verizon have agreed to hold off on installing their new cellphone antennas near airports for six months. But the problem has not been

Author

Prasenjit Mitra
Professor of Information Sciences and Technology, Penn State

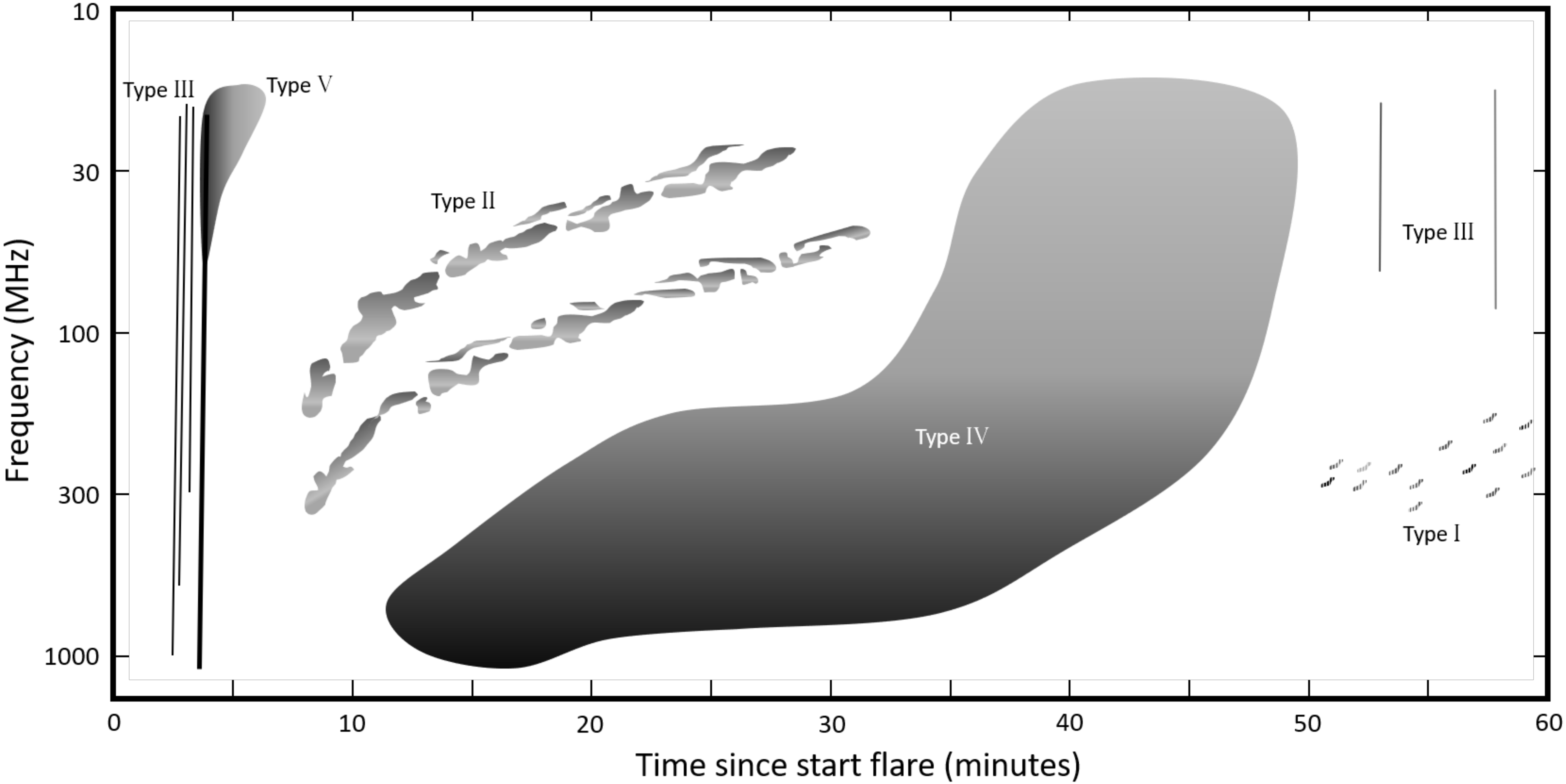
Disclosure statement

Vol. I – Overview of spectrum for aviation



Notes:
Drawing not to scale
Not all Regional or sub-Regional allocations are shown
Band identification (e.g. VHF) and band # per Radio Regulations
The satellite communication bands used by MTSAT and Inmarsat are not allocated the the Aeronautical Mobile Satellte (R) Service

Loftur Jónasson, et al. ICAO



https://www.stce.be/educational/classification

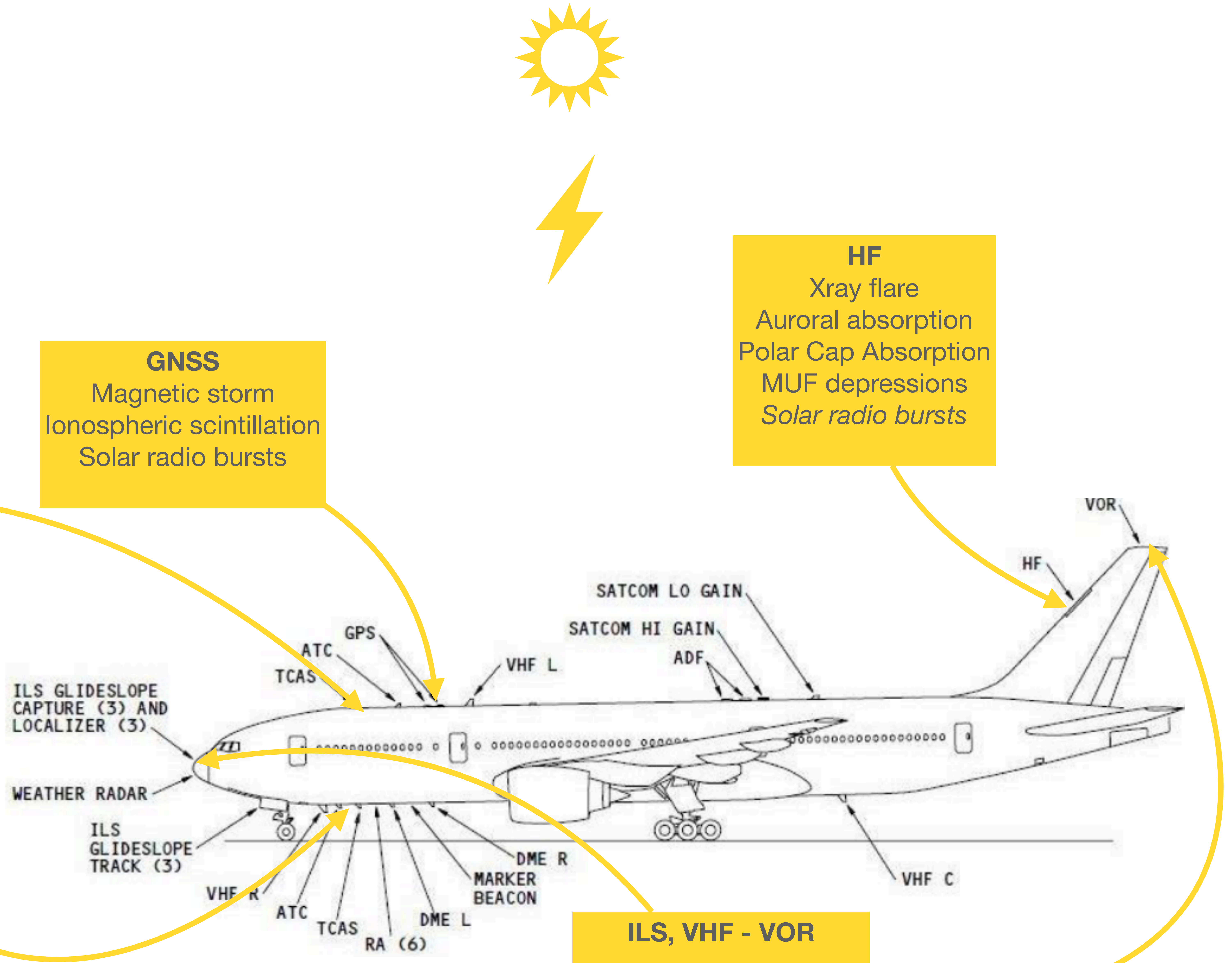
Susceptibility to interferences

First estimate

Calculate the interference level that equals the receiver thermal noise, that is, decrease S/N by 3 dB

$$kT\Delta\nu = \frac{1}{2}G\frac{\lambda^2}{4\pi}F$$

Bala et al., 2002



ATC, TCAS, DME

Solar radio bursts (ATC)

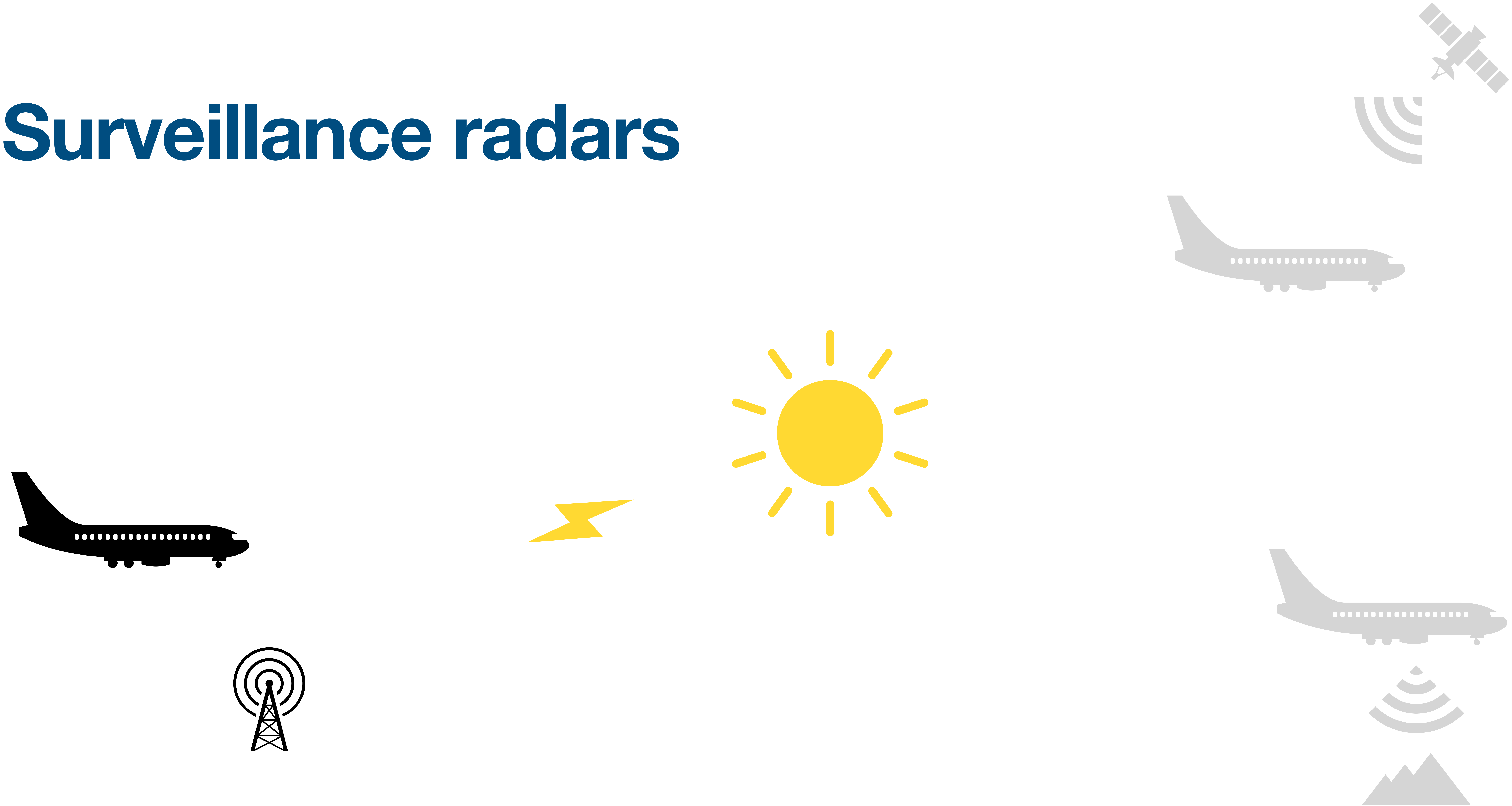
GNSS
Magnetic storm
Ionospheric scintillation
Solar radio bursts

HF
Xray flare
Auroral absorption
Polar Cap Absorption
MUF depressions
Solar radio bursts

ILS, VHF - VOR

Solar radio bursts
Ionospheric scintillations
Geomagnetic storms

Surveillance radars



Impact on radars

Military devices - UK, World War II

110 m

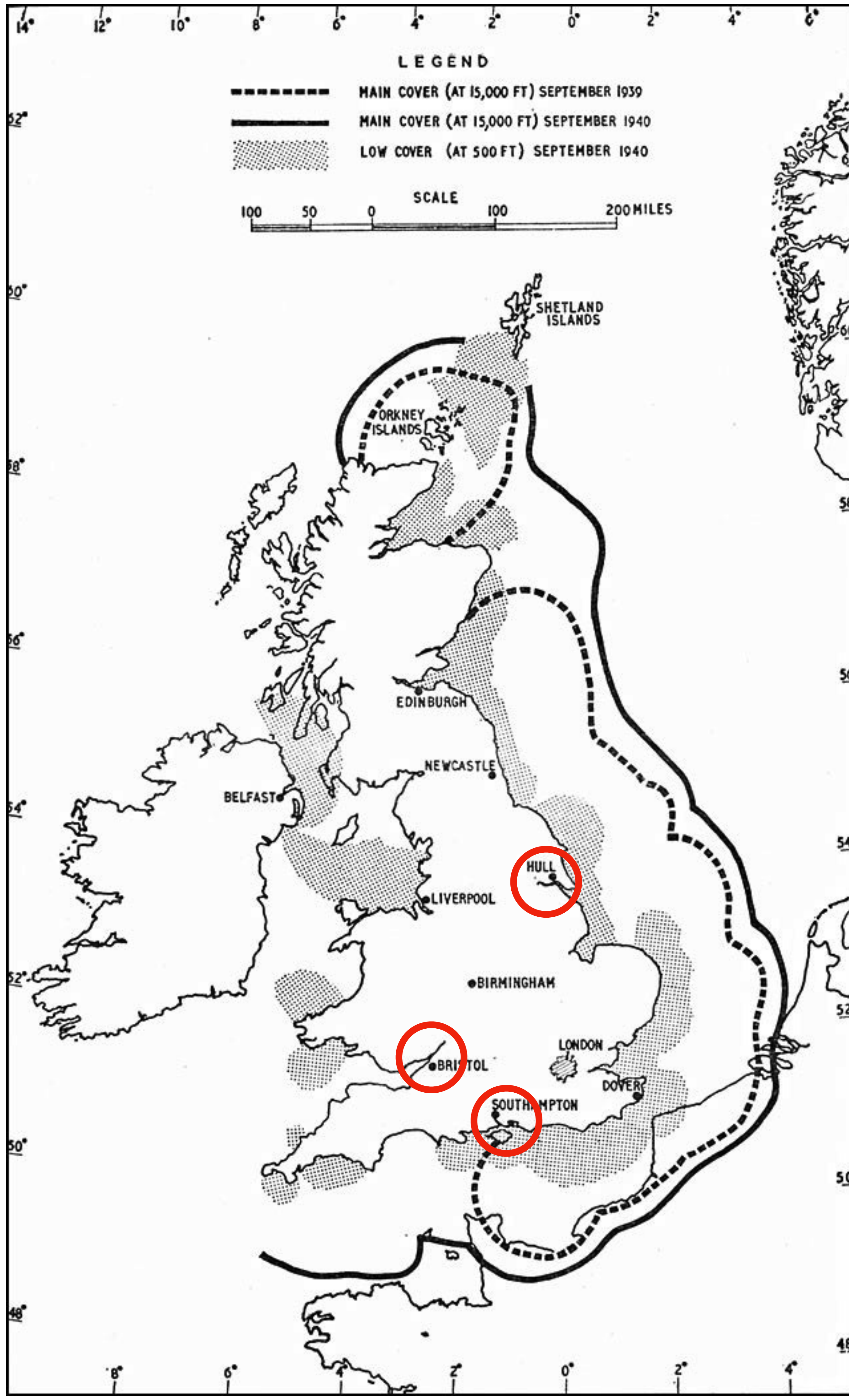
Receiving wooden towers

73 m

Transmission steel towers (4)

One of the Chain Home radar stations, in the UK

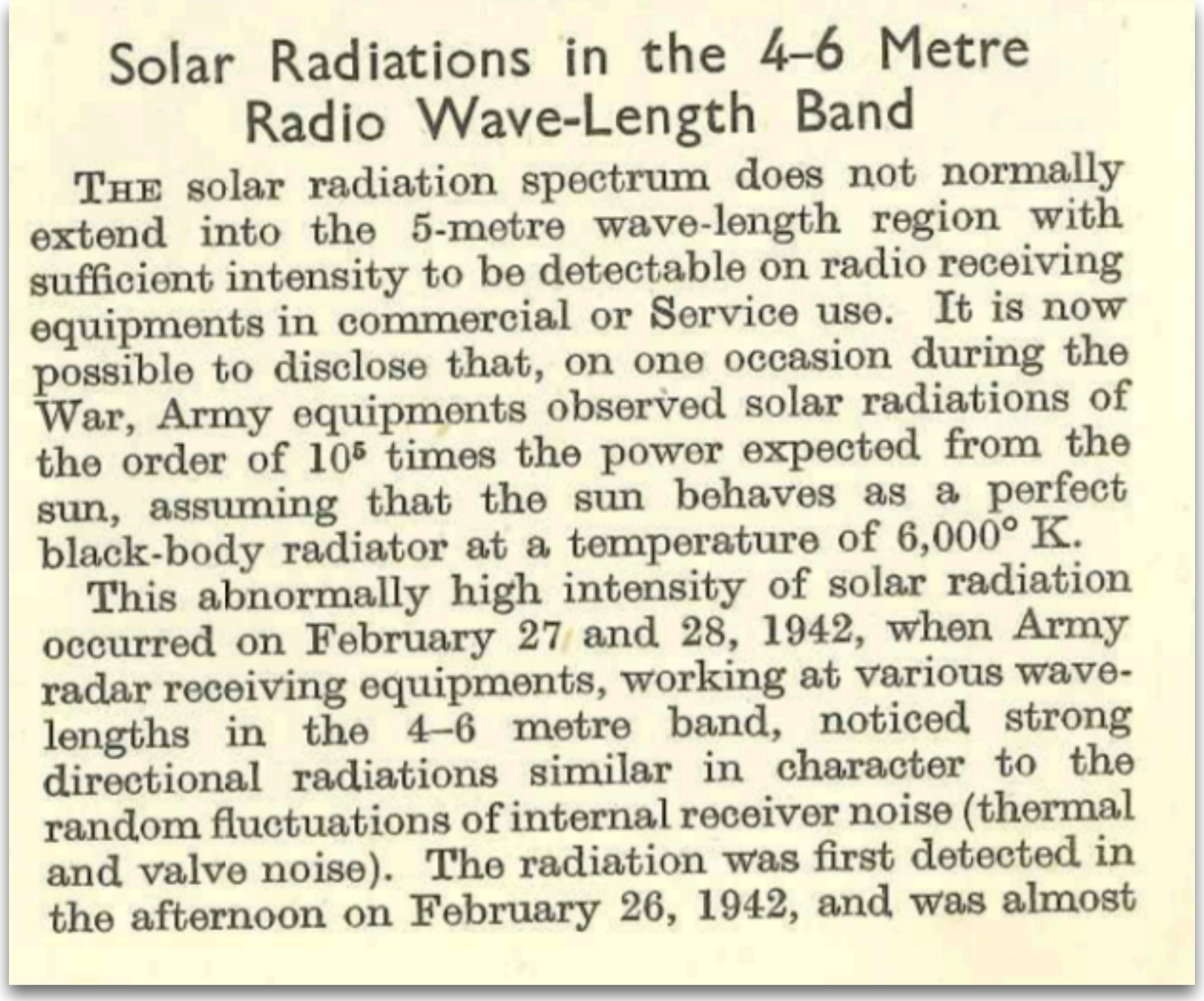
from the collections of the Imperial War Museums, Public domain



WIKIPEDIA

Impact on radars

Military devices - UK, World War II

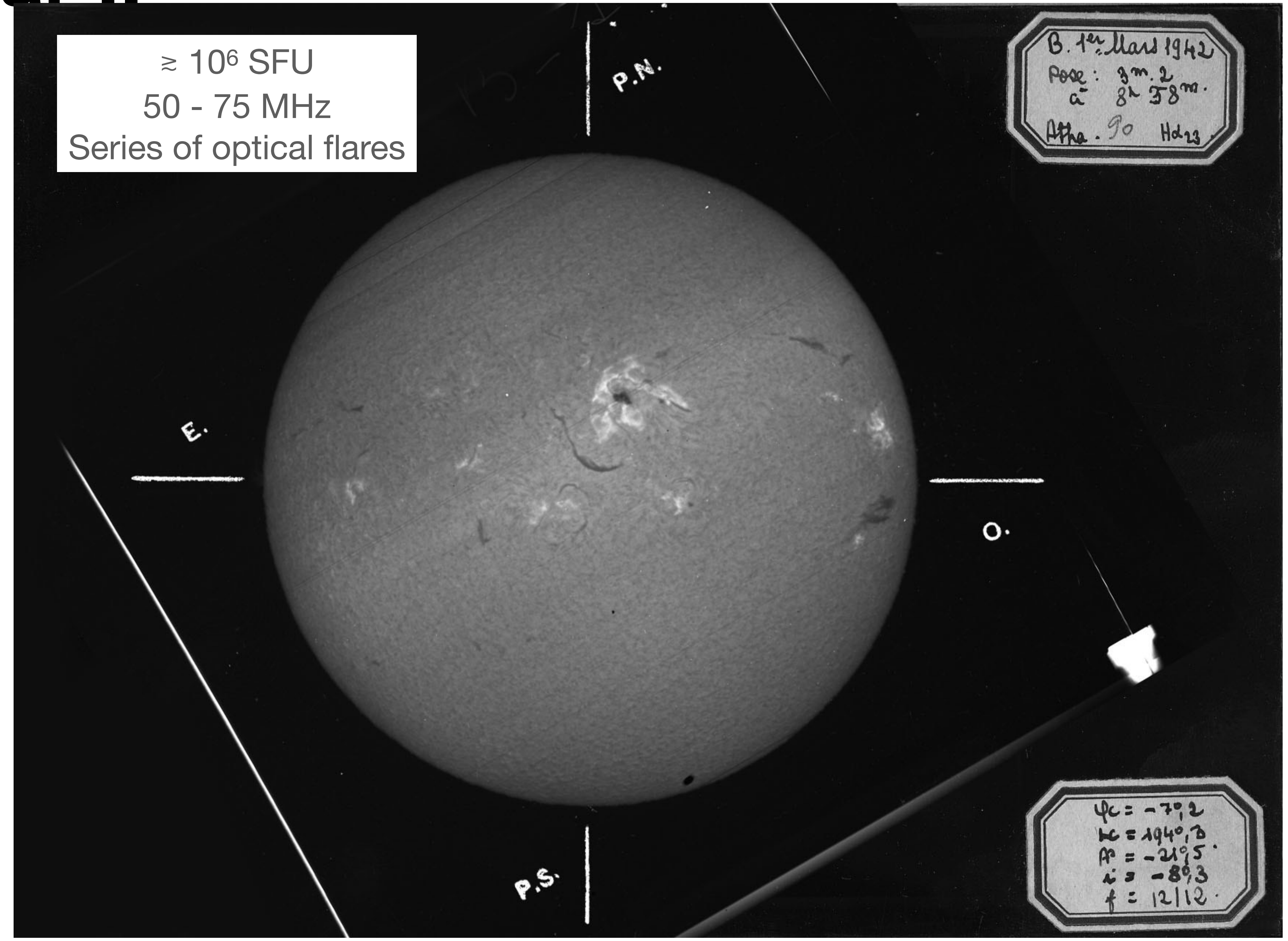


Solar Radiations in the 4–6 Metre Radio Wave-Length Band

THE solar radiation spectrum does not normally extend into the 5-metre wave-length region with sufficient intensity to be detectable on radio receiving equipments in commercial or Service use. It is now possible to disclose that, on one occasion during the War, Army equipments observed solar radiations of the order of 10^5 times the power expected from the sun, assuming that the sun behaves as a perfect black-body radiator at a temperature of 6,000° K.

This abnormally high intensity of solar radiation occurred on February 27 and 28, 1942, when Army radar receiving equipments, working at various wave-lengths in the 4–6 metre band, noticed strong directional radiations similar in character to the random fluctuations of internal receiver noise (thermal and valve noise). The radiation was first detected in the afternoon on February 26, 1942, and was almost

Hey, 1946



$\gtrsim 10^6$ SFU

50 - 75 MHz

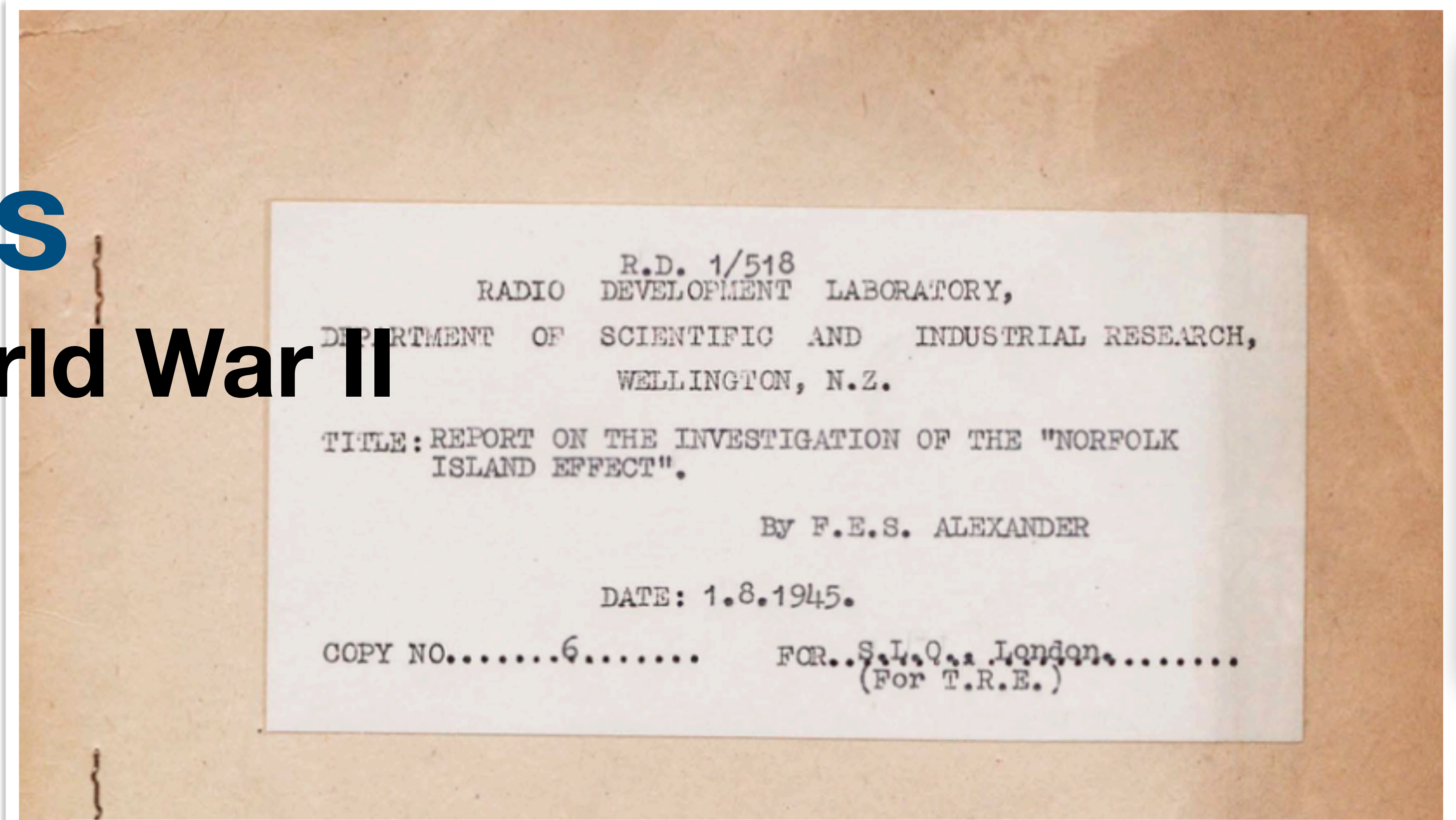
Series of optical flares

source: https://observations-solaires.obspm.fr/

Impact on radars

Military radars - NZ, World War II

- In March - April1945, Royal New Zealand Air Force radar station on the Norfolk Island picked up increase level of noise at Sun rise and Sun set at 200 MHz
- The head of the ORS of Radio Development Lab., Elisabeth Alexander investigated it, with new measurements and linked it to the Sun itself



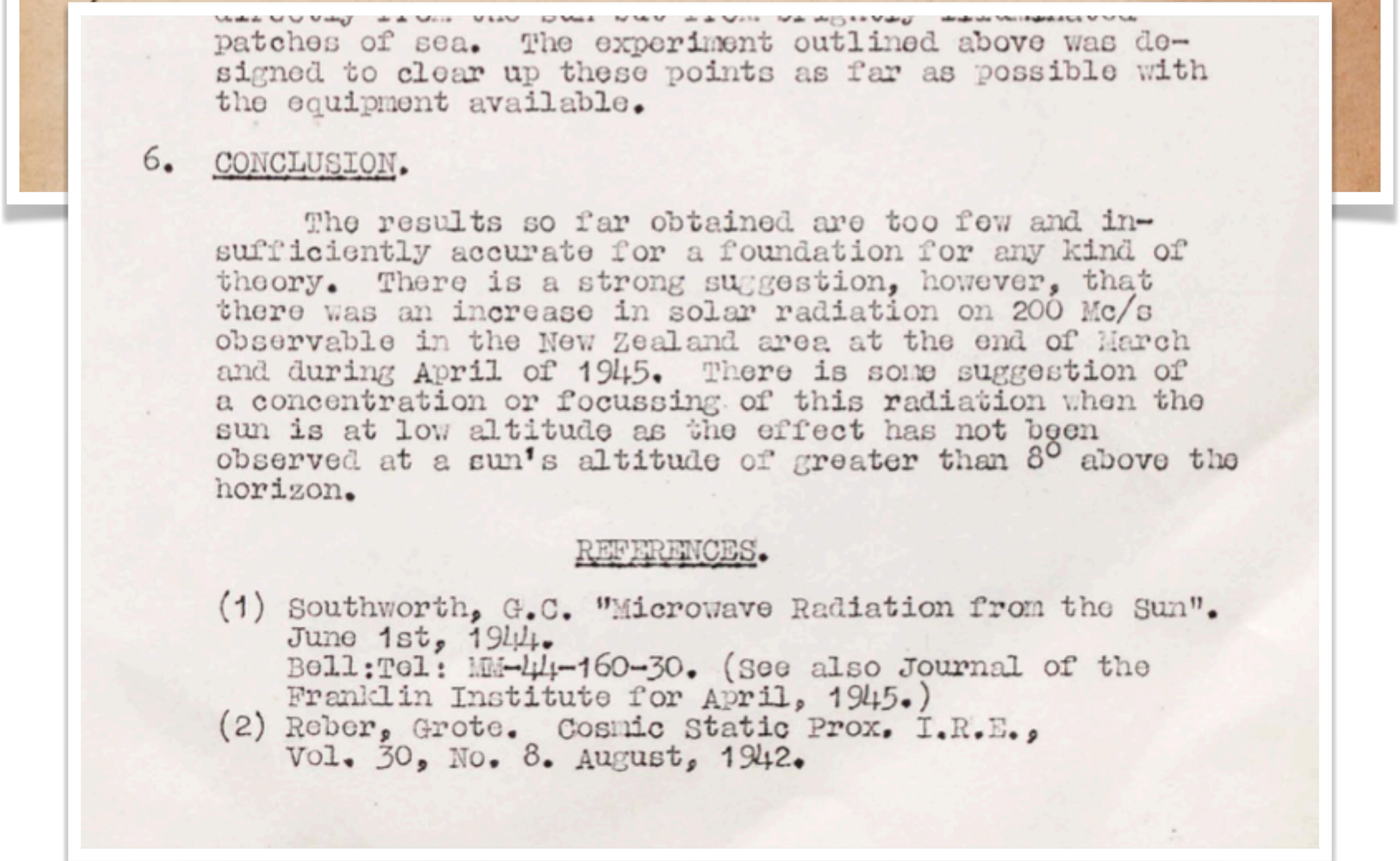
R.D. 1/518
RADIO DEVELOPMENT LABORATORY,
DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH,
WELLINGTON, N.Z.

TITLE: REPORT ON THE INVESTIGATION OF THE "NORFOLK ISLAND EFFECT".

By F.E.S. ALEXANDER

DATE: 1.8.1945.

COPY NO.......6....... FOR..S.L.O., London.........
(For T.R.E.)



patches of sea. The experiment outlined above was designed to clear up these points as far as possible with the equipment available.

6. CONCLUSION.

The results so far obtained are too few and insufficiently accurate for a foundation for any kind of theory. There is a strong suggestion, however, that there was an increase in solar radiation on 200 Mc/s observable in the New Zealand area at the end of March and during April of 1945. There is some suggestion of a concentration or focussing of this radiation when the sun is at low altitude as the effect has not been observed at a sun's altitude of greater than 8° above the horizon.

REFERENCES.

(1) Southworth, G.C. "Microwave Radiation from the Sun". June 1st, 1944.
Bell:Tel: MM-44-160-30. (See also Journal of the Franklin Institute for April, 1945.)
(2) Reber, Grote. Cosmic Static Prox. I.R.E., Vol. 30, No. 8. August, 1942.

Elizabeth Alexander

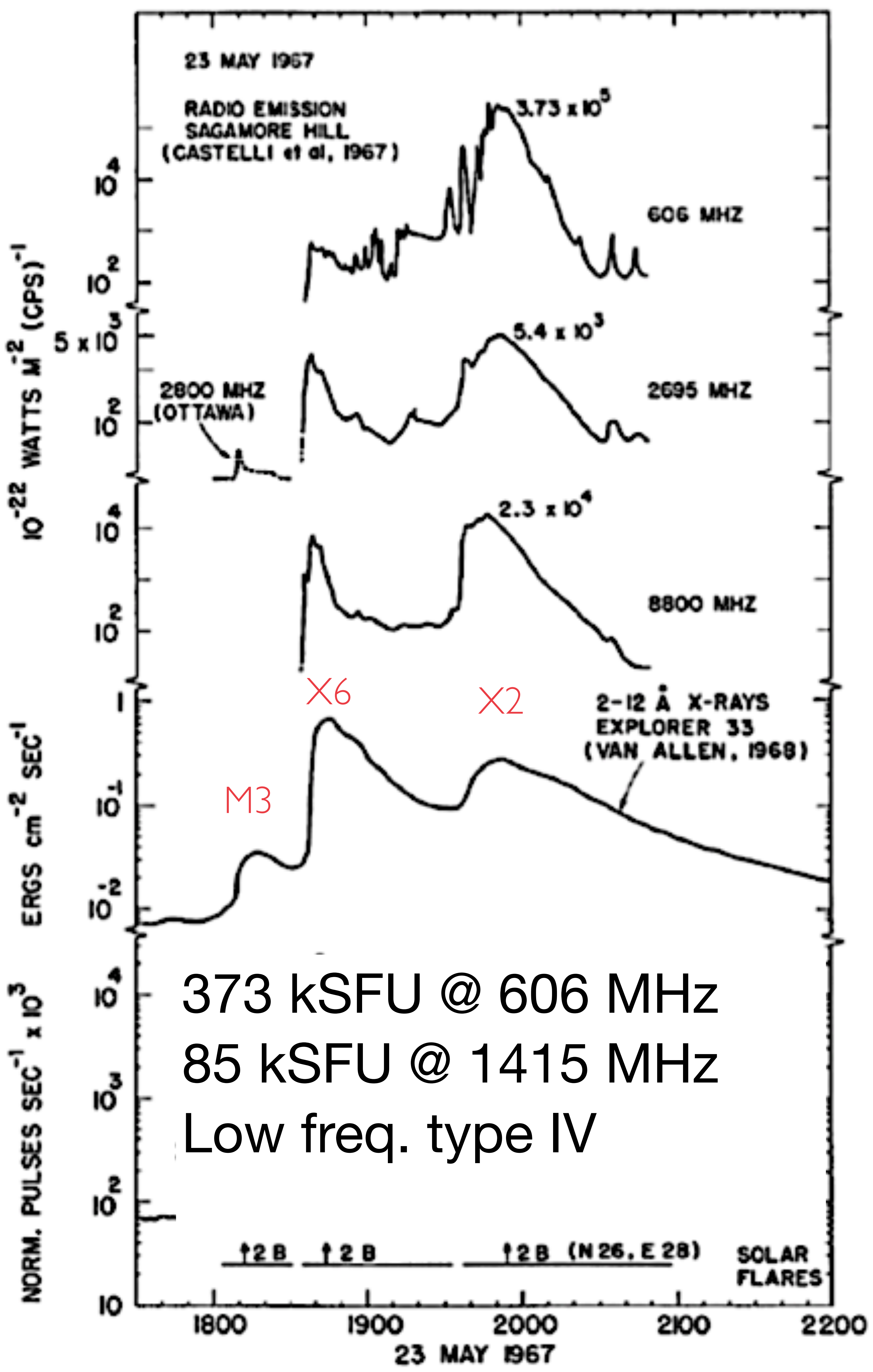
Likely the radar picked up intense noise storm emission from sunspot groups

Impact on radars

Military devices - Cold war

Jamming of Ballistic Missile Early Warning System (BMEWS) radars at 440 MHz

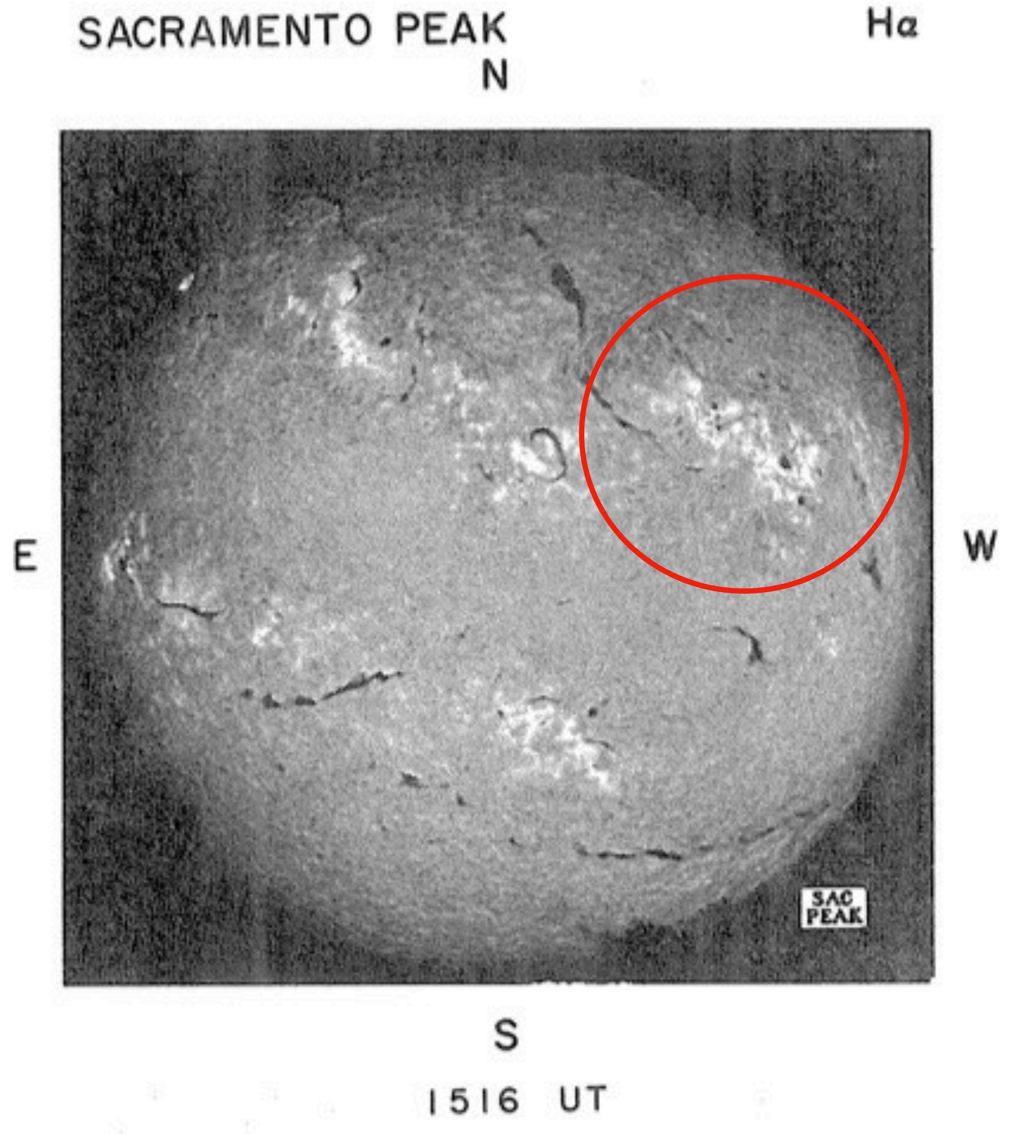
"Cold War military commanders viewed full scale jamming of surveillance sensors as a potential act of war. (...) the online memorial tributes to Col C. K. Anderson, (...) clearly credit him and his NORAD solar forecasting staff (...) with providing the information that eventually calmed nerves and allowed aircraft engines to cool as they returned to normal alert stance."

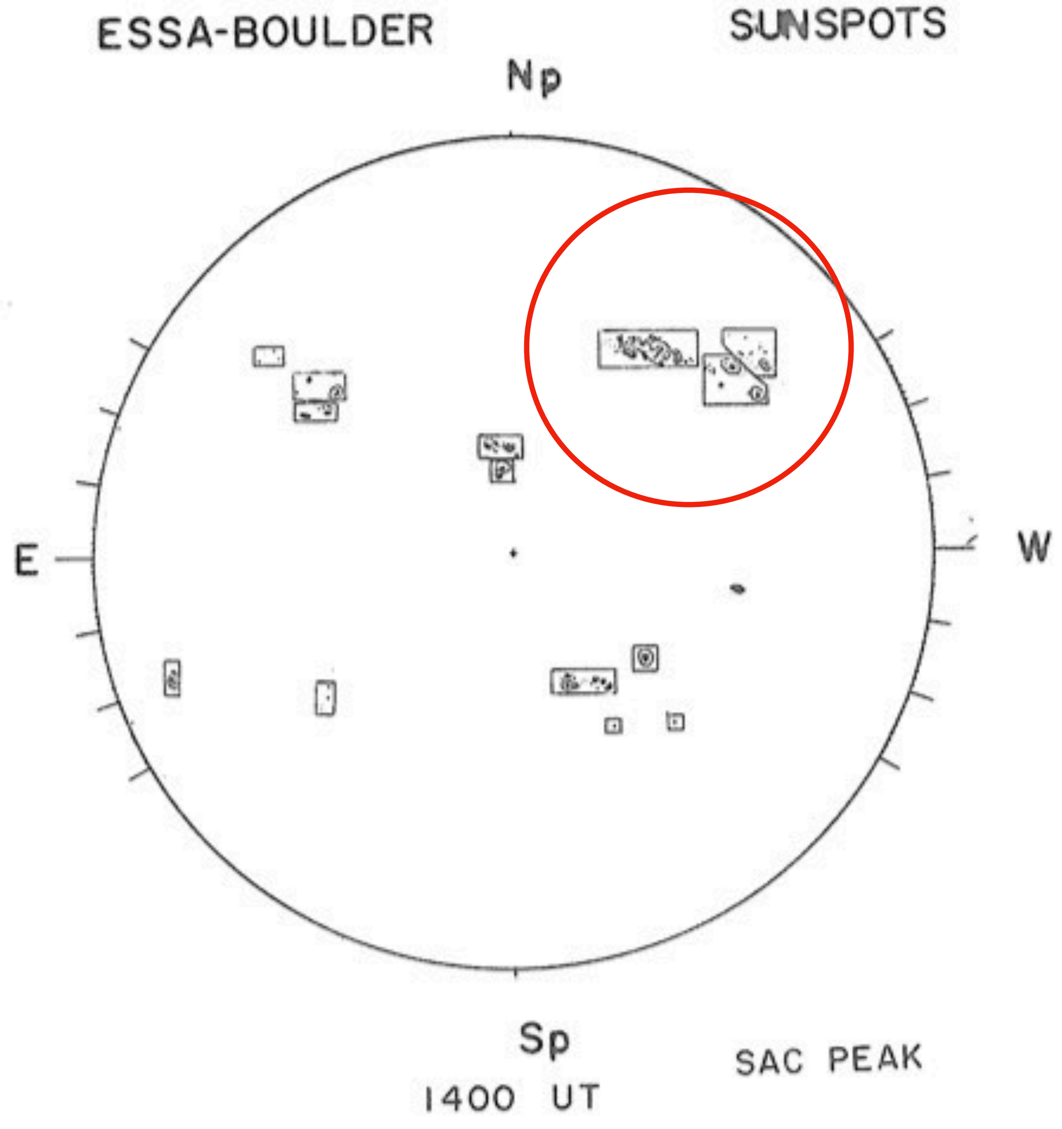


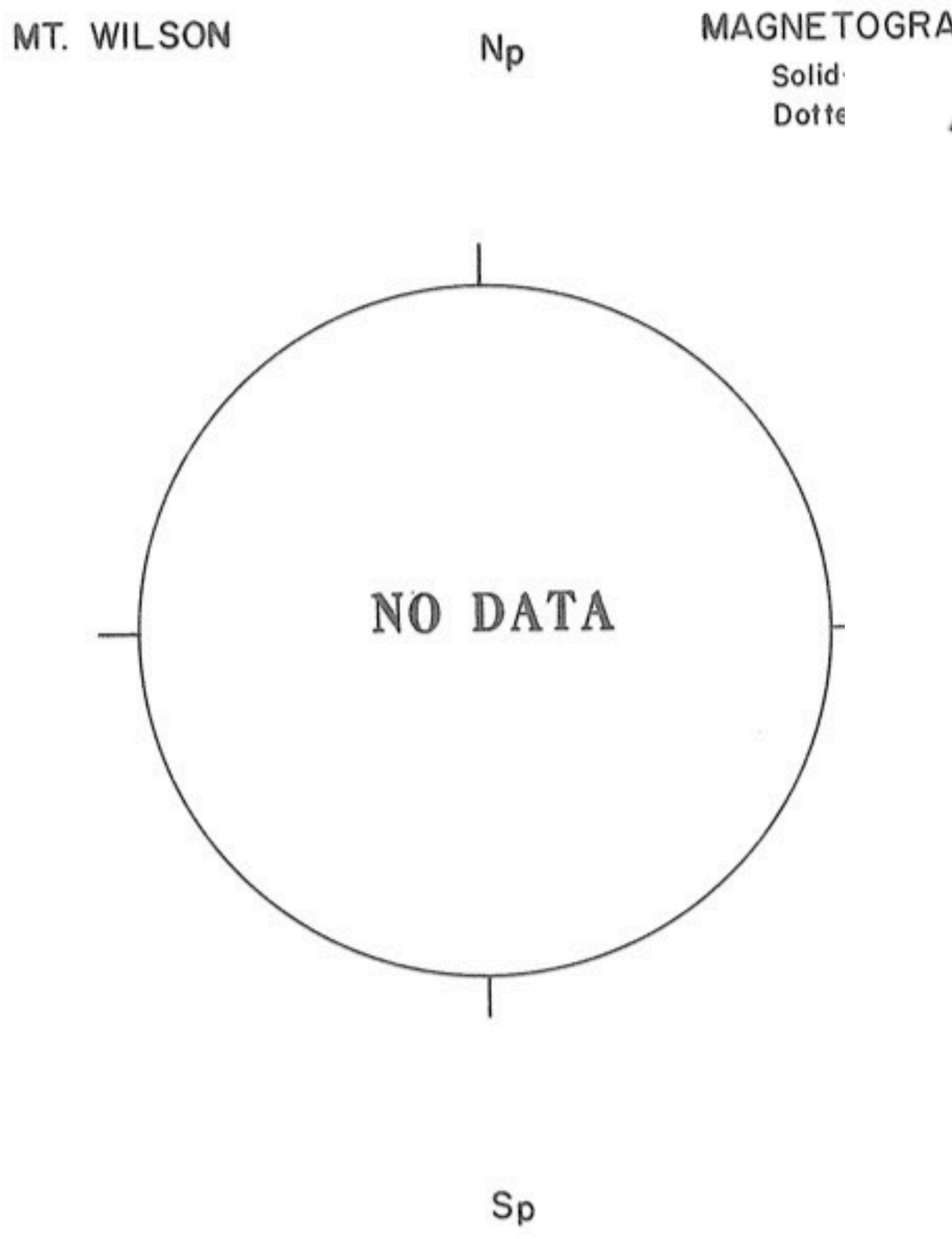
373 kSFU @ 606 MHz
85 kSFU @ 1415 MHz
Low freq. type IV

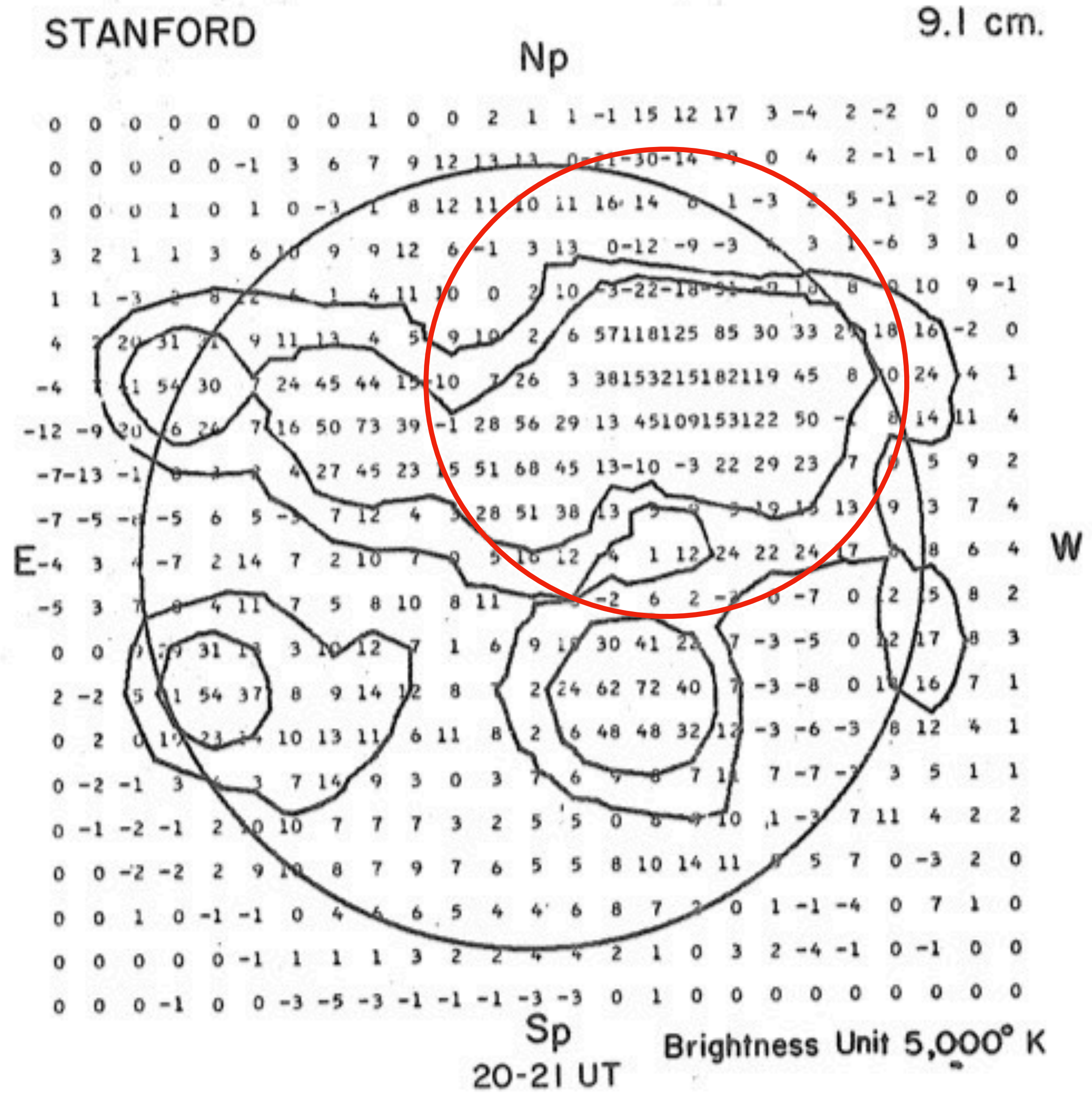
Knipp et al. 2016

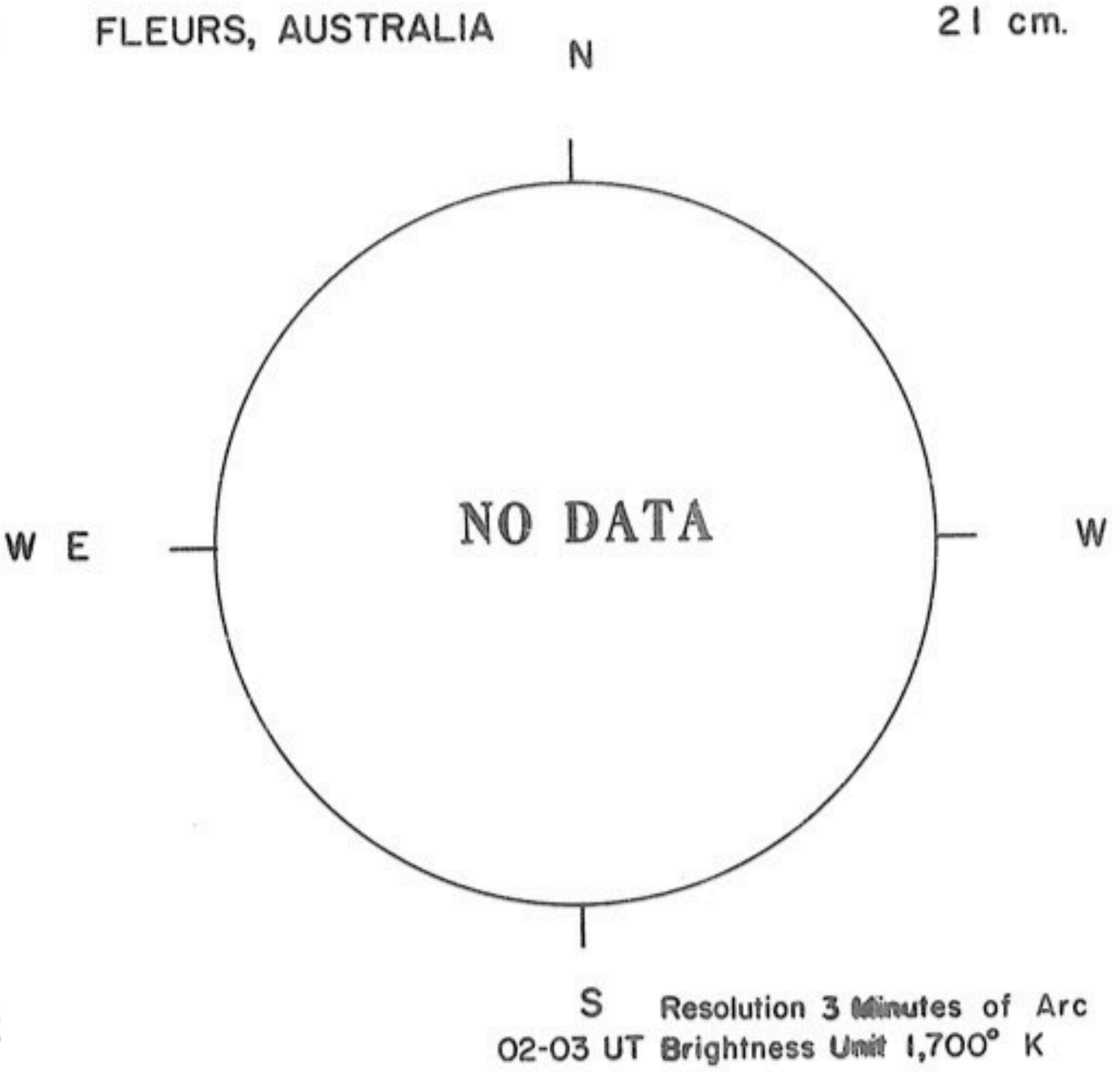
MAY 27, 1967 (P=-17.51, B_o=-1.29, L_o=207.53)

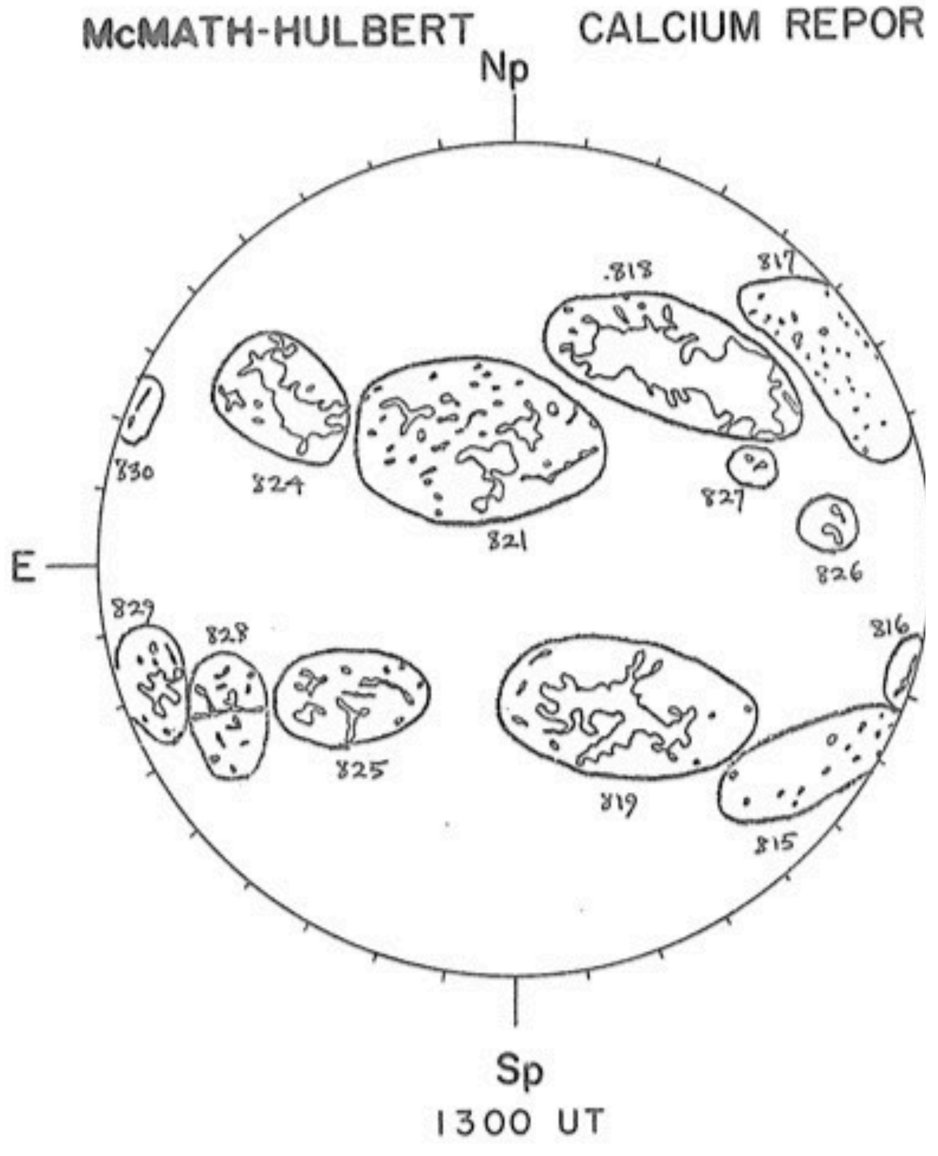


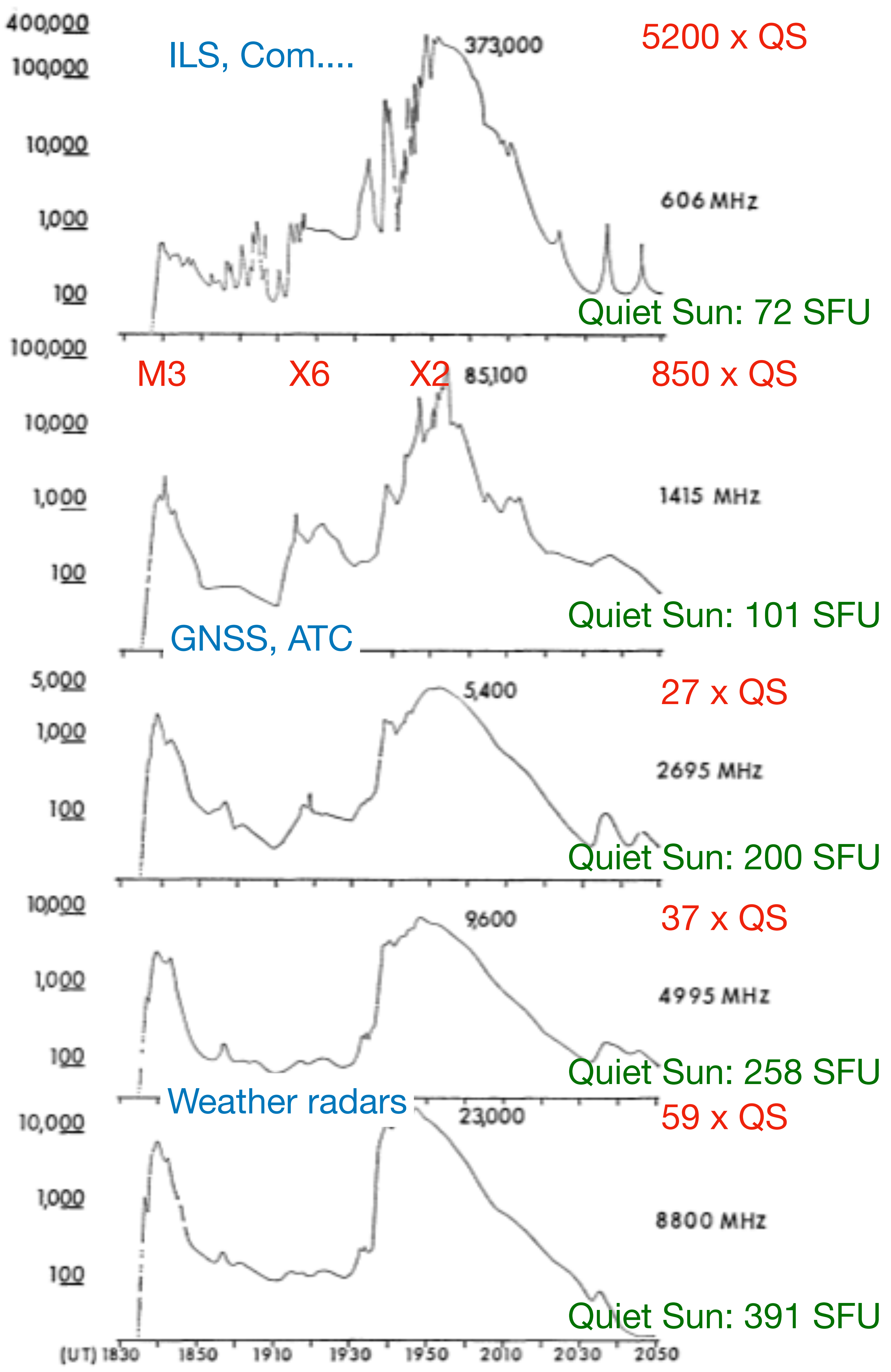










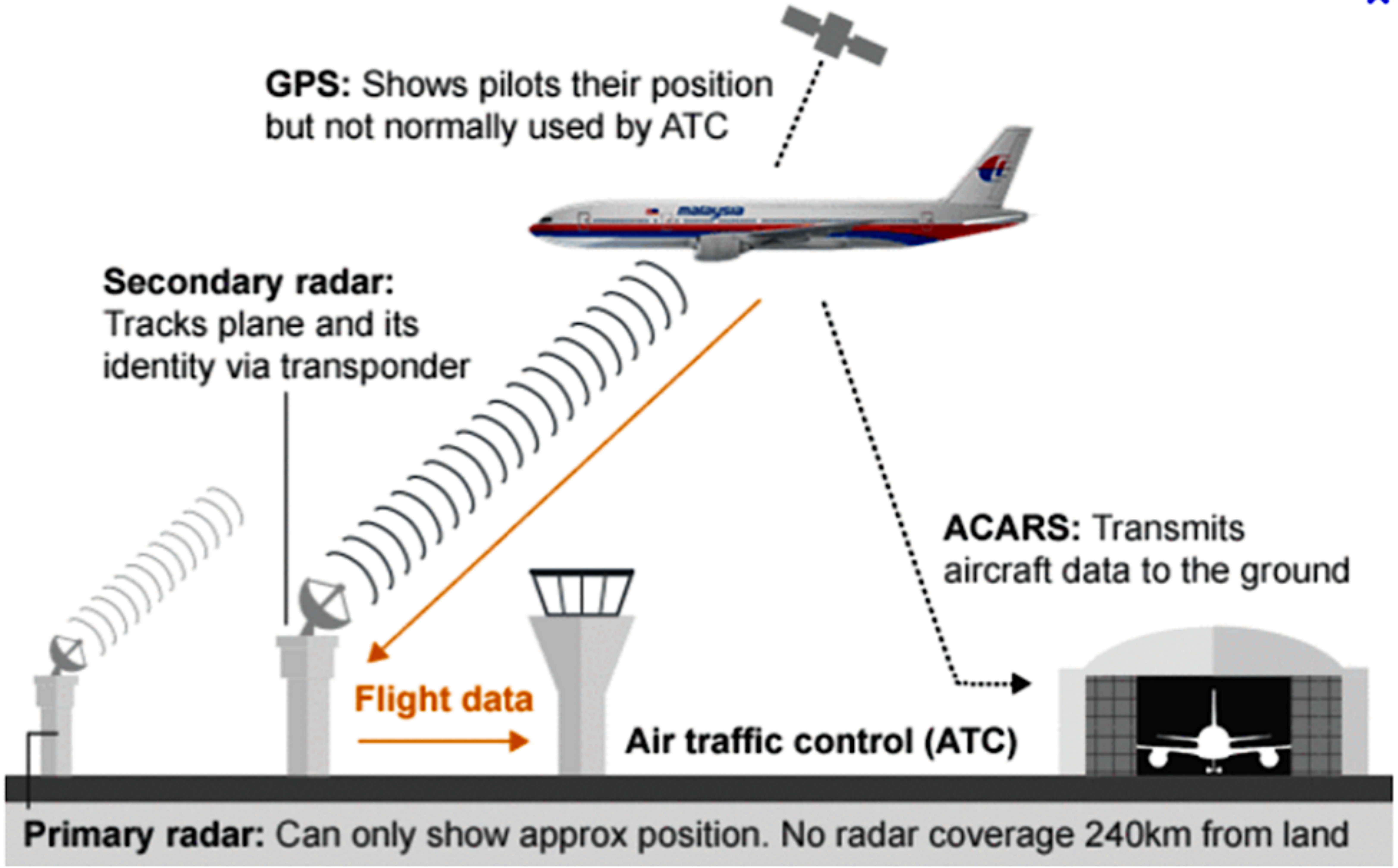


Air traffic radars

Civil aviation

Primary radars : 2800 MHz

Secondary radars: 1030 & 1090 MHz



Source: BBC

November 4 2015

A media storm

- ATC radars in Sweden suffered severe disturbances between 14:20 UT and 16:00 UT
- Incoming flights were deviated, no departures allowed
- Geomagnetic storm was initially considered as the source of disturbances (media)

thewatchers.adorraeli.com/2015/11/05/the-sweden-case-aircrafts-disappear-from-radars-due-to-solar-storm/

The Sweden Case: Airplanes disappear from radars due to "solar storm"

Posted by Adonai on November 05, 2015 in categories Featured articles, Geomagnetic storms, Solar activity

Monday, June 13, 2016 / 09:44 UTC

www.usatoday.com/story/travel/roadwarriorvoices/2015/11/07/solar-storm-made-every-plane-in-sweden-disappear-from-the-countrys-radar-screens/83312456/

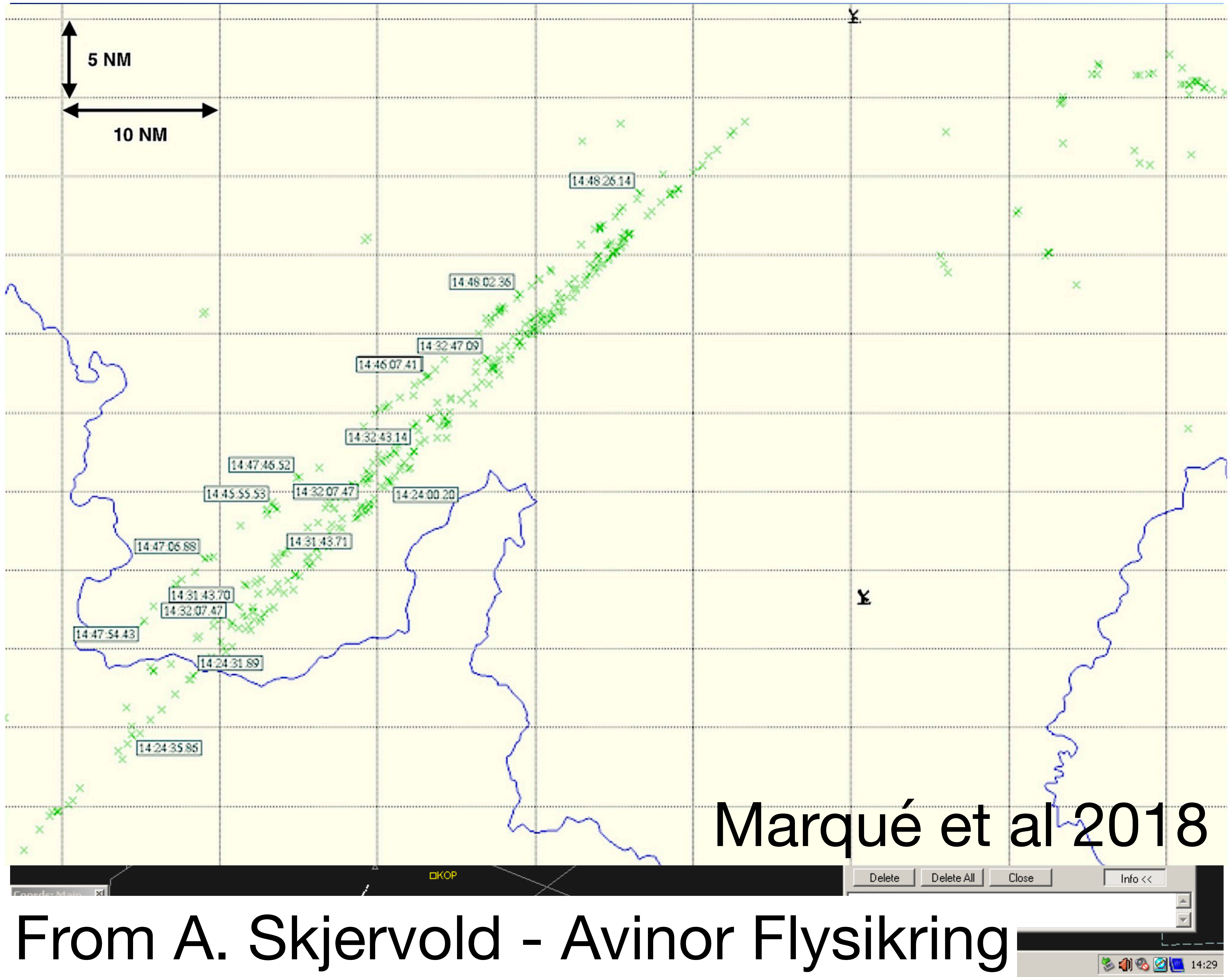
Solar storm made every plane in Sweden disappear from the country's radar screens

Jelisa Castrodale, USA TODAY 9 a.m. EST November 7, 2015

Photo: NASA Goddard Space Flight Center/Flickr

A European wide disruption

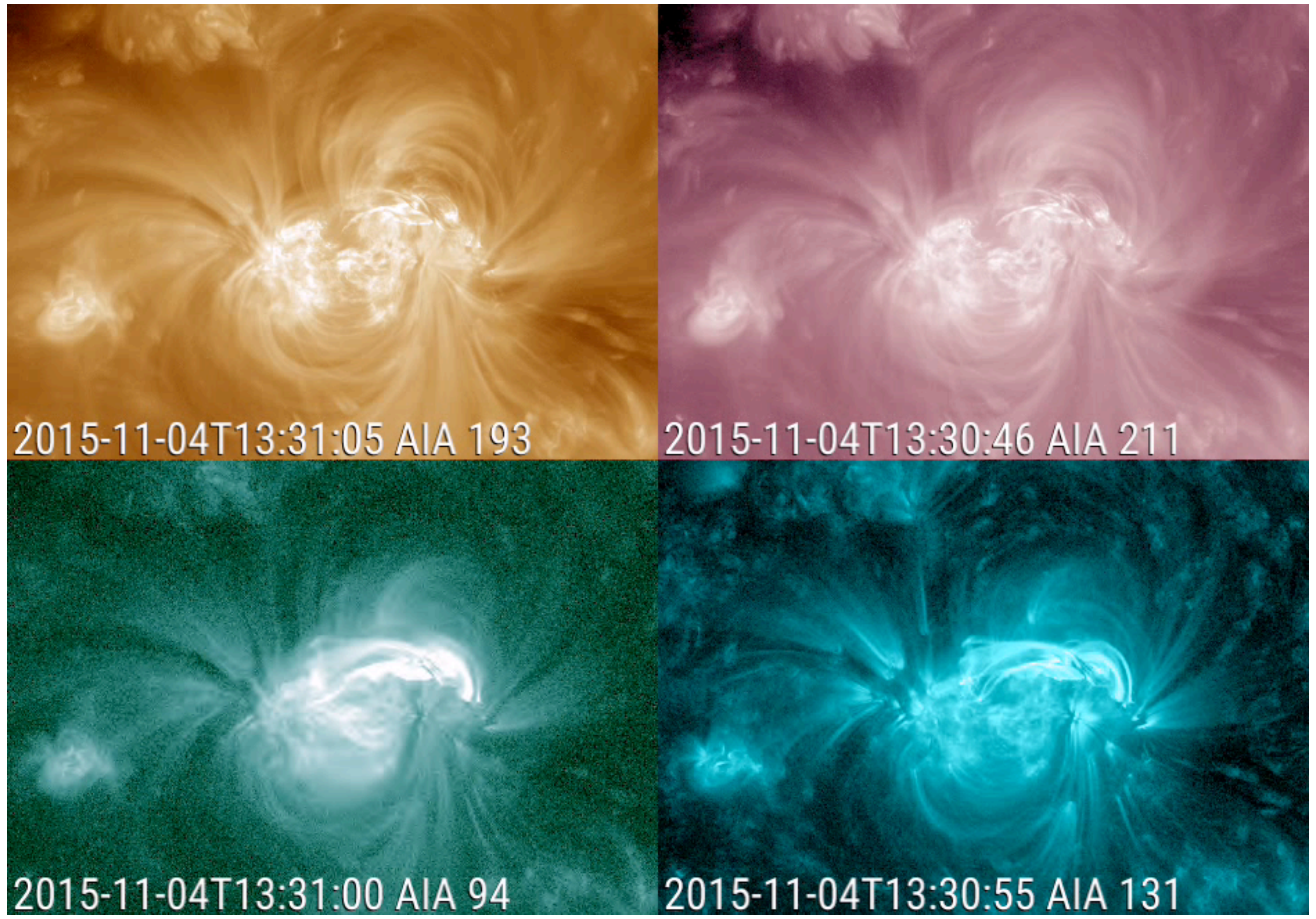
- Sweden: ATC radars suffered severe disturbances
  14:20 UT - 16:00 UT
- Sweden: Partial closure of air space for an hour
- Minor disturbances in Norway, Belgium

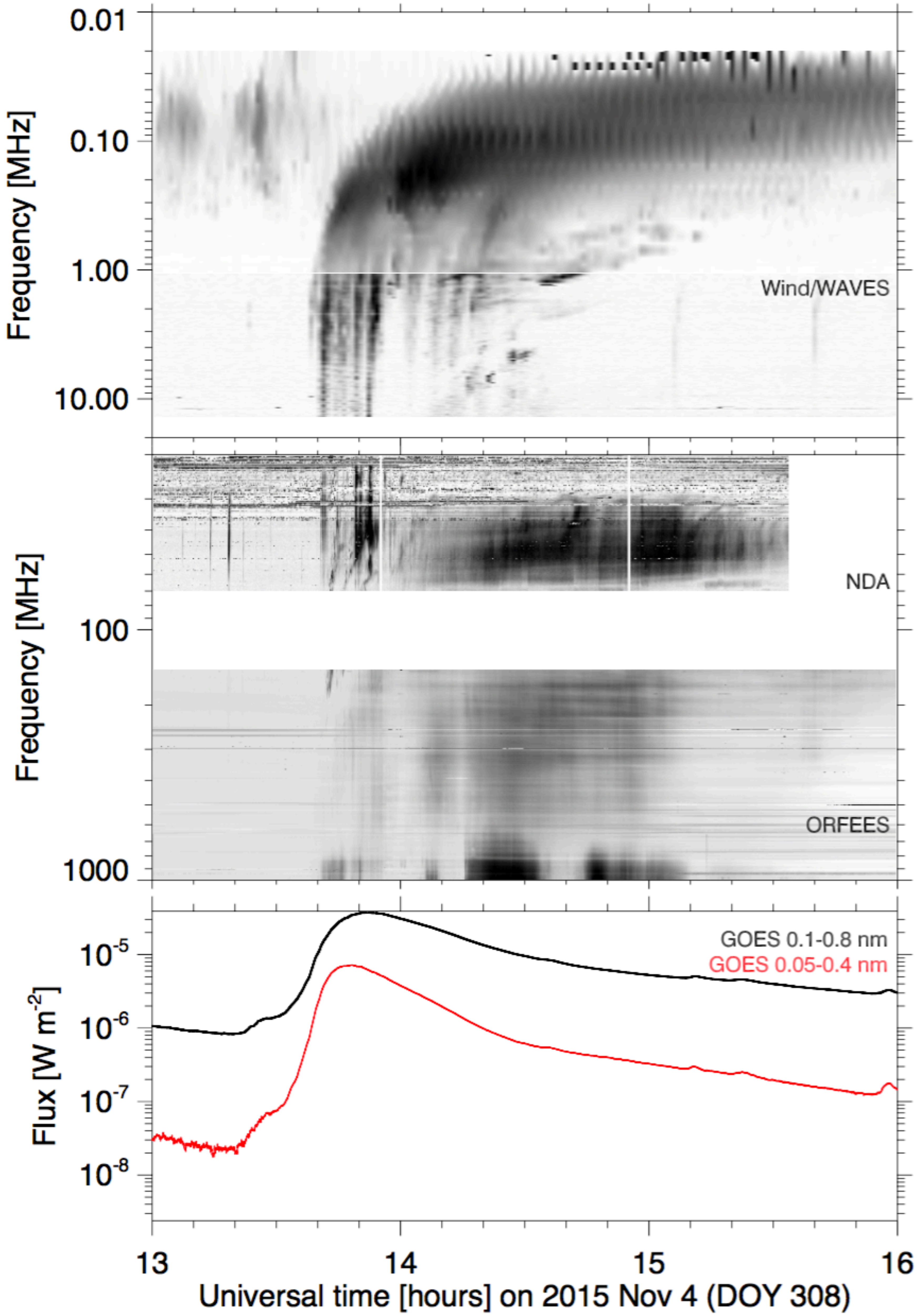


Marqué et al 2018

From A. Skjervold - Avinor Flysikring

Solar event

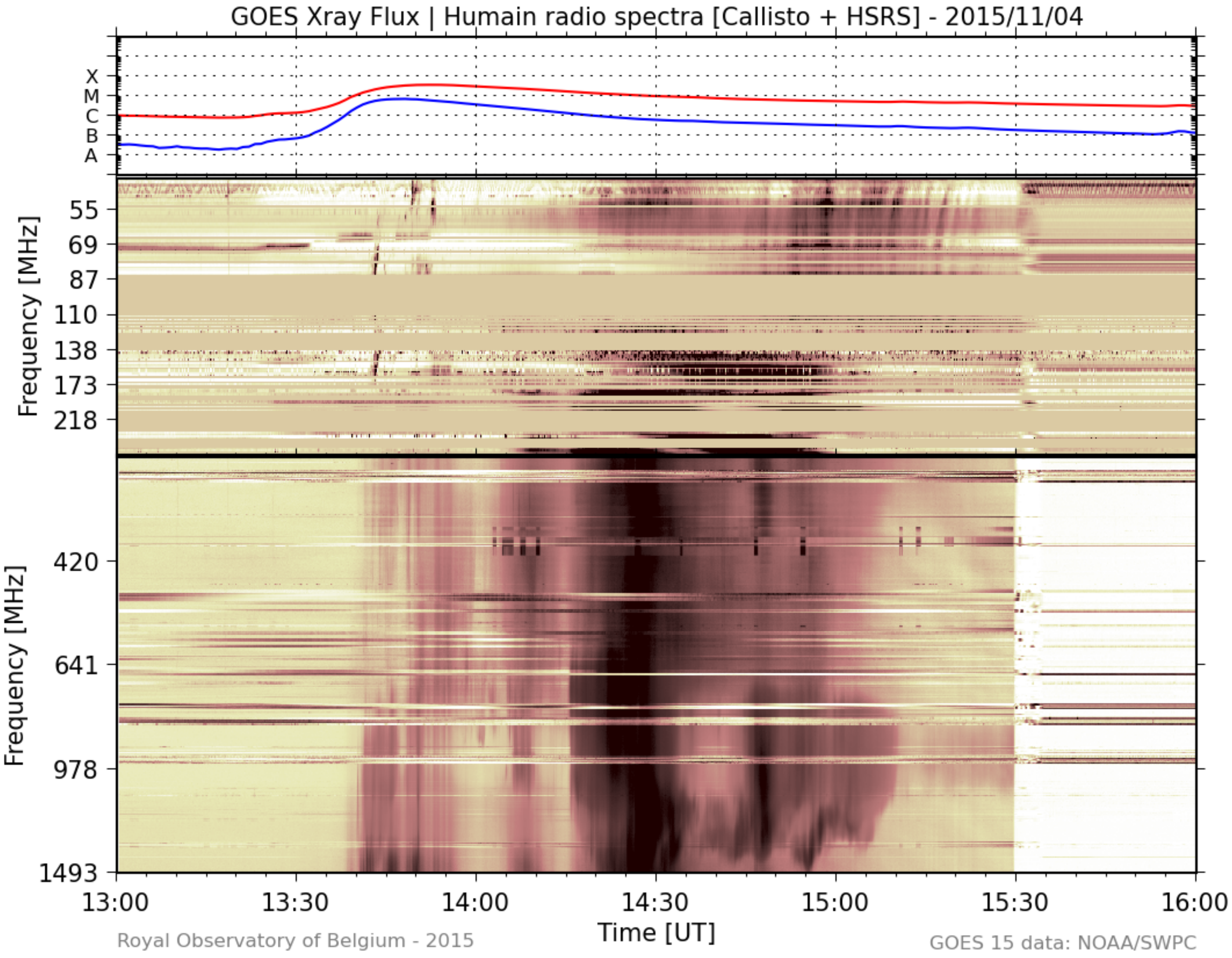




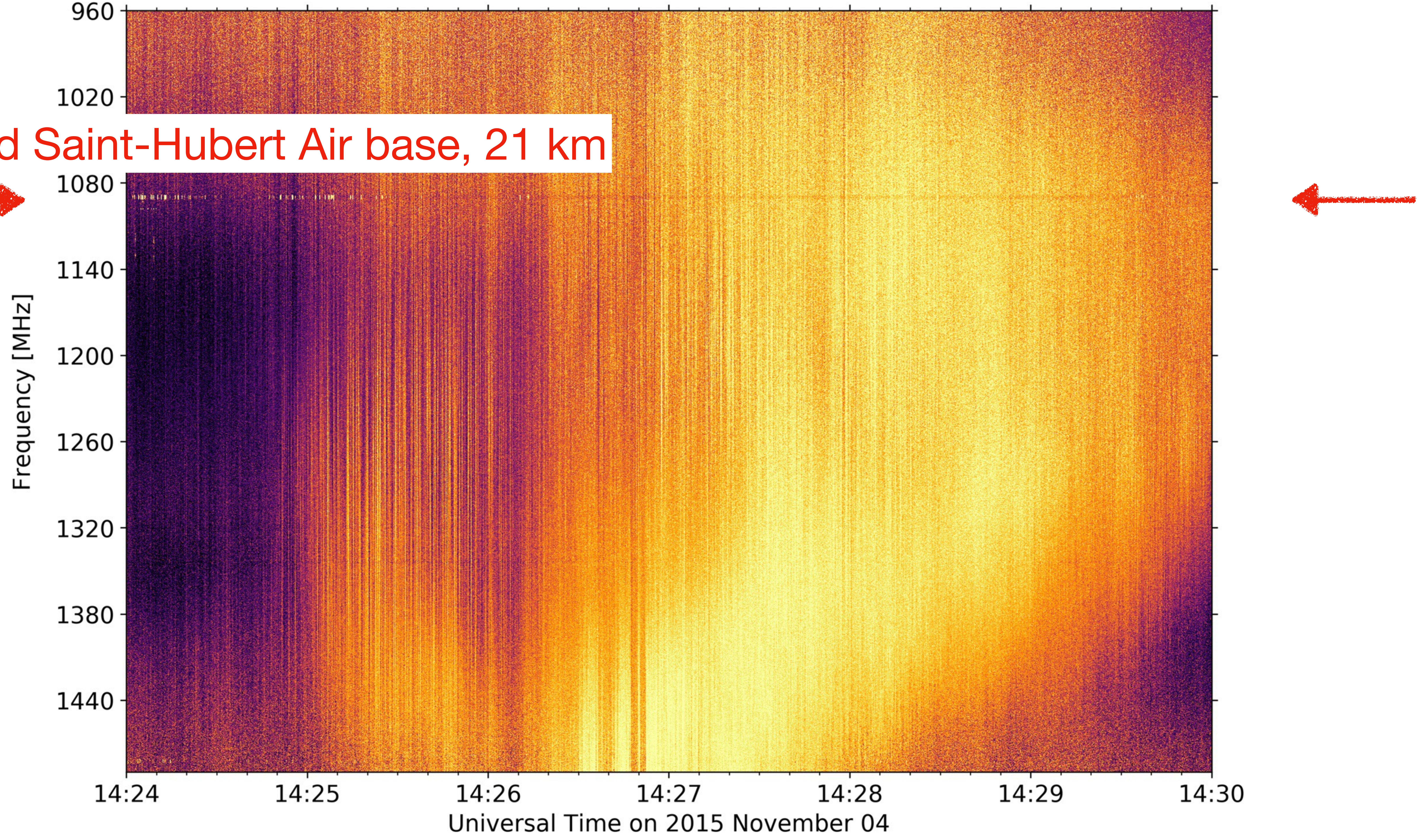
M3.7 flare peaking @1352 UT
NOAA AR 2243

In Humain

http://sidc.be/humain



Radar band Saint-Hubert Air base, 21 km



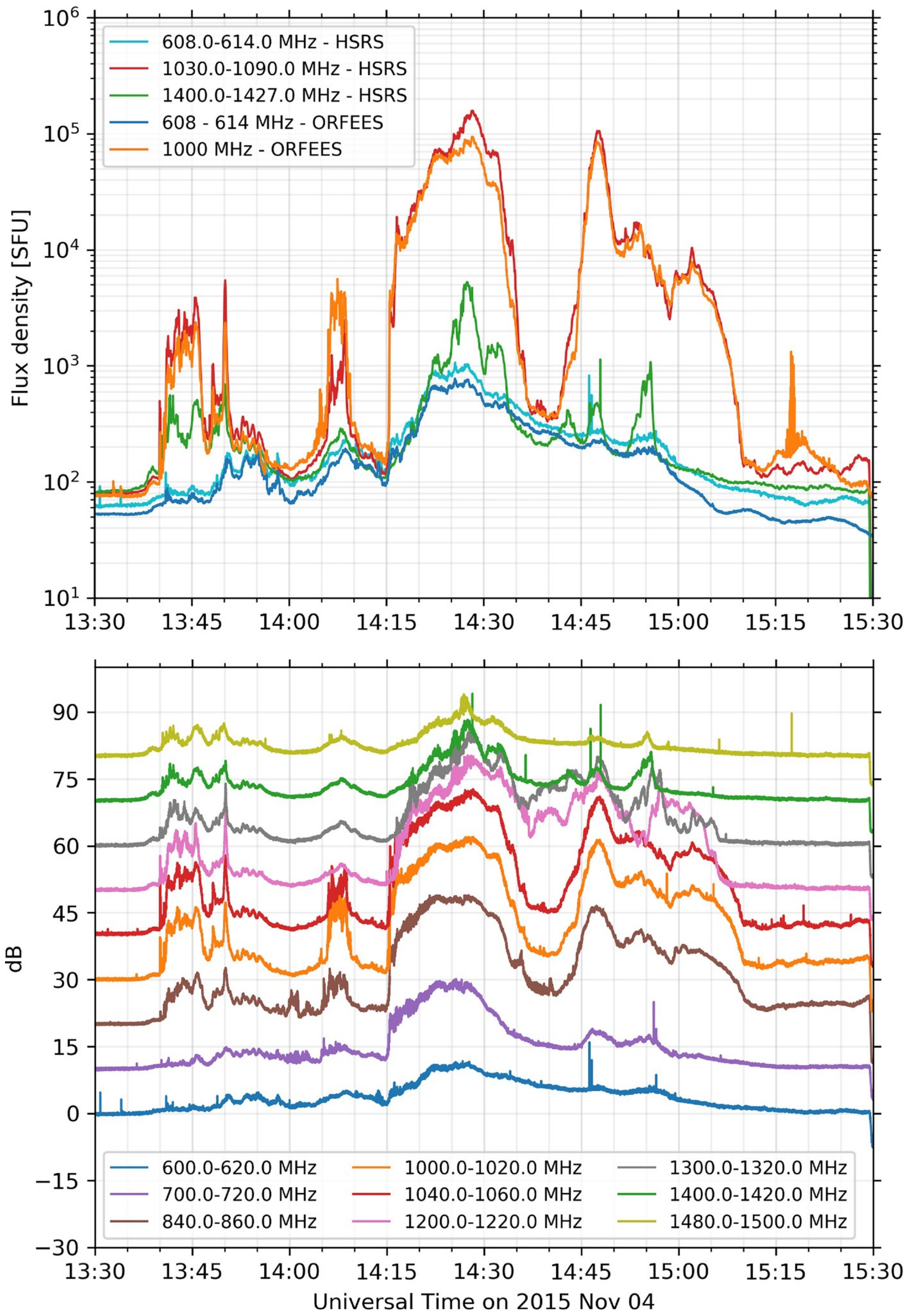
An exceptional event?

Strong magnitude

ORFEES (1000 MHz)🇫🇷	100 kSFU
Blein (1000 – 1250 MHz) 🇨🇭	123 kSFU
Humain (1060 MHz)🇧🇪	157 kSFU

But...

610 MHz 🇫🇷🇧🇪	820 - 1000 SFU
1415 – 1427 MHz 🇨🇭🇧🇪🇺🇸	5200 - 6300 SFU



Interference threshold comparison

- The interference threshold for such radars is about **-102 dBm** ($6{,}3 \cdot 10^{-14}$ W) at receiver input.
- The quiet sun level on that day was about 75 SFU ($75 \cdot 10^{-22}$ $W.m^{-2}.Hz^{-1}$), which results in a power at receiver input of **-101 dBm**
- At the peak of the burst the Sun emission level was more than 100 000 SFU, which gives at least a power at receiver input of **-68 dBm**

34 dB above interference threshold (~ 2500 times that level)

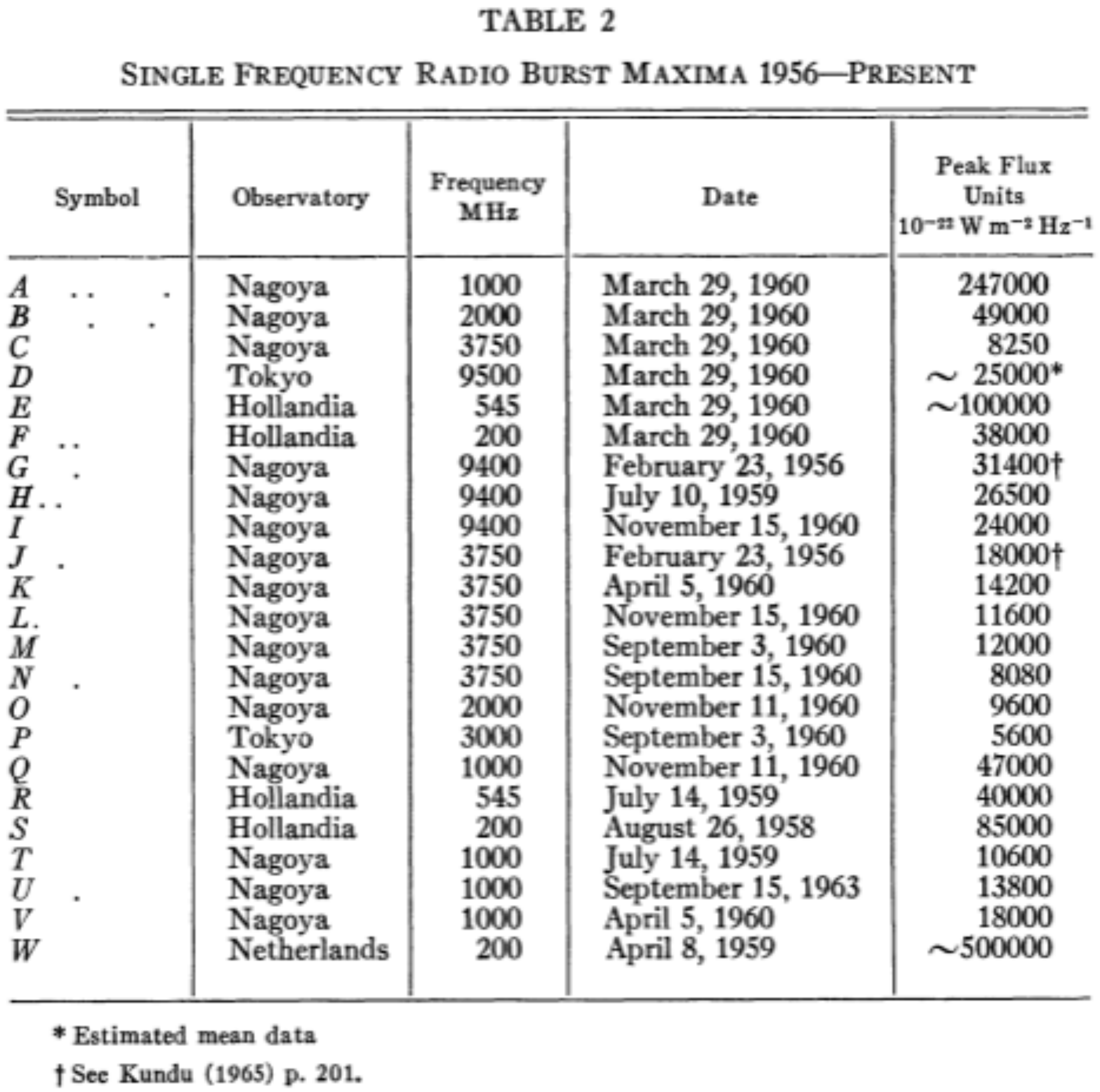


TABLE 2

SINGLE FREQUENCY RADIO BURST MAXIMA 1956—PRESENT

Symbol	Observatory	Frequency MHz	Date	Peak Flux Units 10^{-22} W m^{-2} Hz^{-1}
A	Nagoya	1000	March 29, 1960	247000
B	Nagoya	2000	March 29, 1960	49000
C	Nagoya	3750	March 29, 1960	8250
D	Tokyo	9500	March 29, 1960	~ 25000*
E	Hollandia	545	March 29, 1960	~100000
F	Hollandia	200	March 29, 1960	38000
G	Nagoya	9400	February 23, 1956	31400†
H	Nagoya	9400	July 10, 1959	26500
I	Nagoya	9400	November 15, 1960	24000
J	Nagoya	3750	February 23, 1956	18000†
K	Nagoya	3750	April 5, 1960	14200
L	Nagoya	3750	November 15, 1960	11600
M	Nagoya	3750	September 3, 1960	12000
N	Nagoya	3750	September 15, 1960	8080
O	Nagoya	2000	November 11, 1960	9600
P	Tokyo	3000	September 3, 1960	5600
Q	Nagoya	1000	November 11, 1960	47000
R	Hollandia	545	July 14, 1959	40000
S	Hollandia	200	August 26, 1958	85000
T	Nagoya	1000	July 14, 1959	10600
U	Nagoya	1000	September 15, 1963	13800
V	Nagoya	1000	April 5, 1960	18000
W	Netherlands	200	April 8, 1959	~500000

* Estimated mean data

† See Kundu (1965) p. 201.

Castelli, 1968

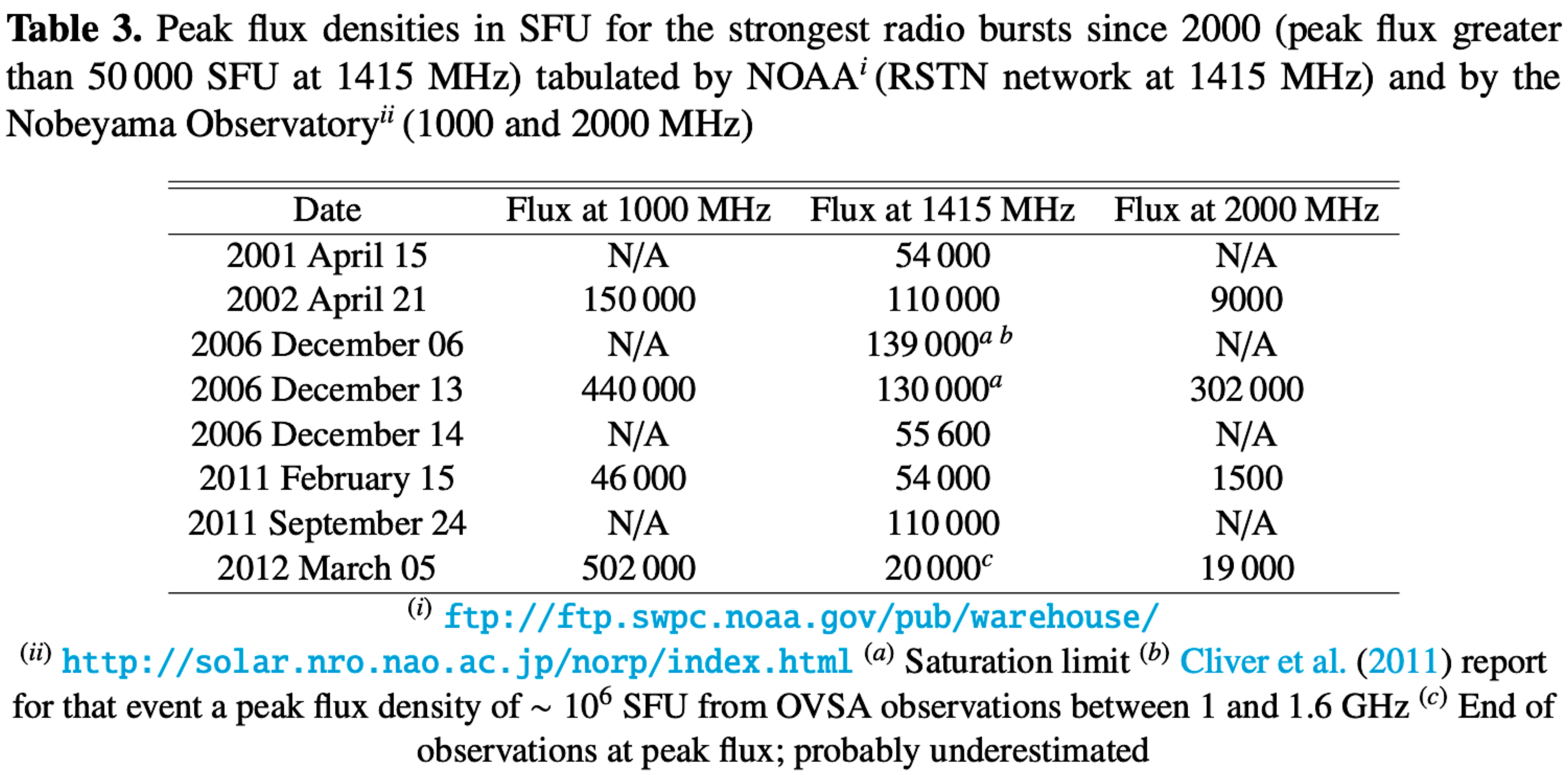


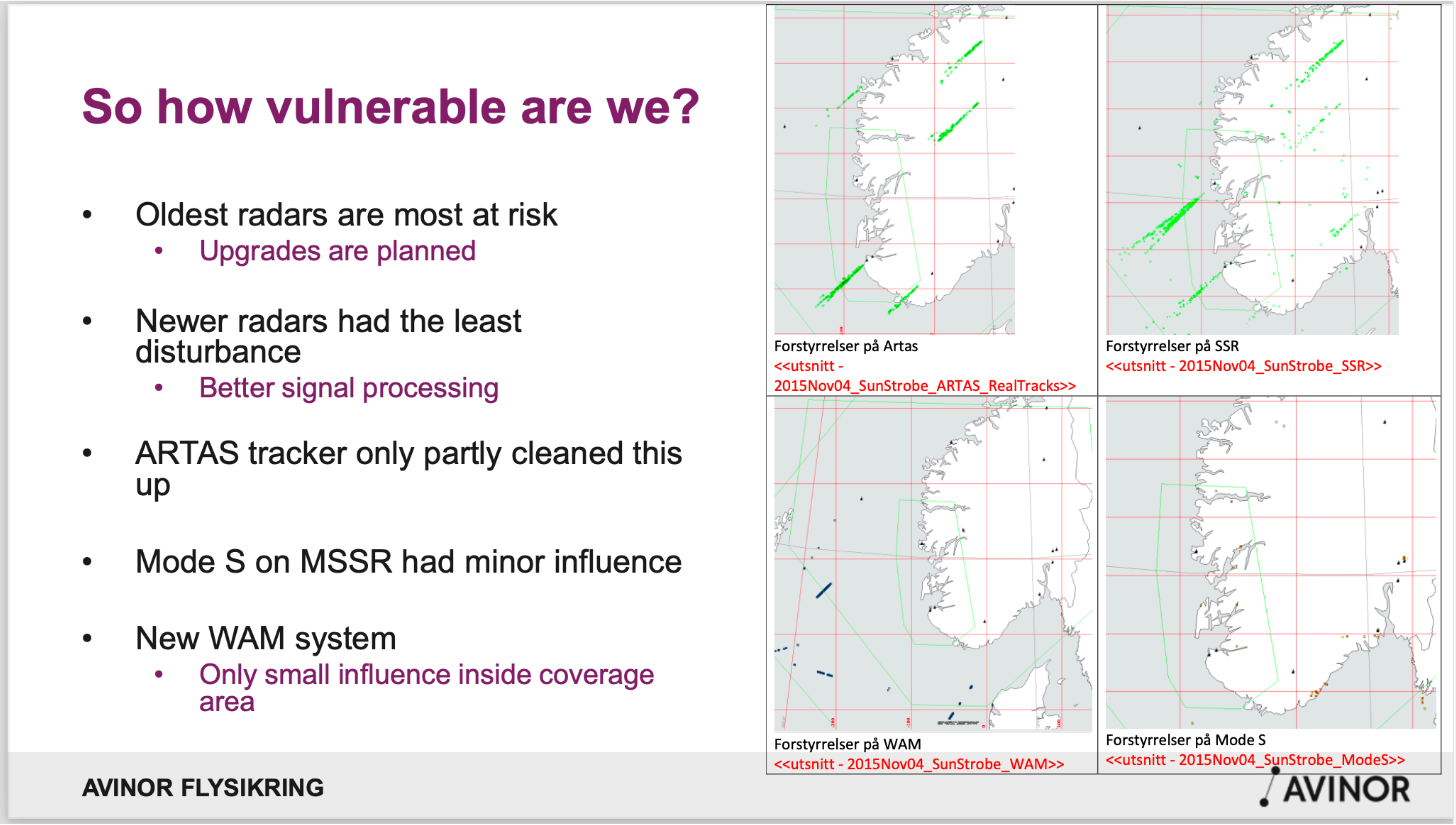
Table 3. Peak flux densities in SFU for the strongest radio bursts since 2000 (peak flux greater than 50 000 SFU at 1415 MHz) tabulated by NOAA[i] (RSTN network at 1415 MHz) and by the Nobeyama Observatory[ii] (1000 and 2000 MHz)

Date	Flux at 1000 MHz	Flux at 1415 MHz	Flux at 2000 MHz
2001 April 15	N/A	54 000	N/A
2002 April 21	150 000	110 000	9000
2006 December 06	N/A	139 000[a b]	N/A
2006 December 13	440 000	130 000[a]	302 000
2006 December 14	N/A	55 600	N/A
2011 February 15	46 000	54 000	1500
2011 September 24	N/A	110 000	N/A
2012 March 05	502 000	20 000[c]	19 000

(i) ftp://ftp.swpc.noaa.gov/pub/warehouse/

(ii) http://solar.nro.nao.ac.jp/norp/index.html (a) Saturation limit (b) Cliver et al. (2011) report for that event a peak flux density of ~ 10^6 SFU from OVSA observations between 1 and 1.6 GHz (c) End of observations at peak flux; probably underestimated

Our own study, 2018



So how vulnerable are we?

- Oldest radars are most at risk
  - Upgrades are planned
- Newer radars had the least disturbance
  - Better signal processing
- ARTAS tracker only partly cleaned this up
- Mode S on MSSR had minor influence
- New WAM system
  - Only small influence inside coverage area

Forstyrrelser på Artas
<<utsnitt - 2015Nov04_SunStrobe_ARTAS_RealTracks>>

Forstyrrelser på SSR
<<utsnitt - 2015Nov04_SunStrobe_SSR>>

Forstyrrelser på WAM
<<utsnitt - 2015Nov04_SunStrobe_WAM>>

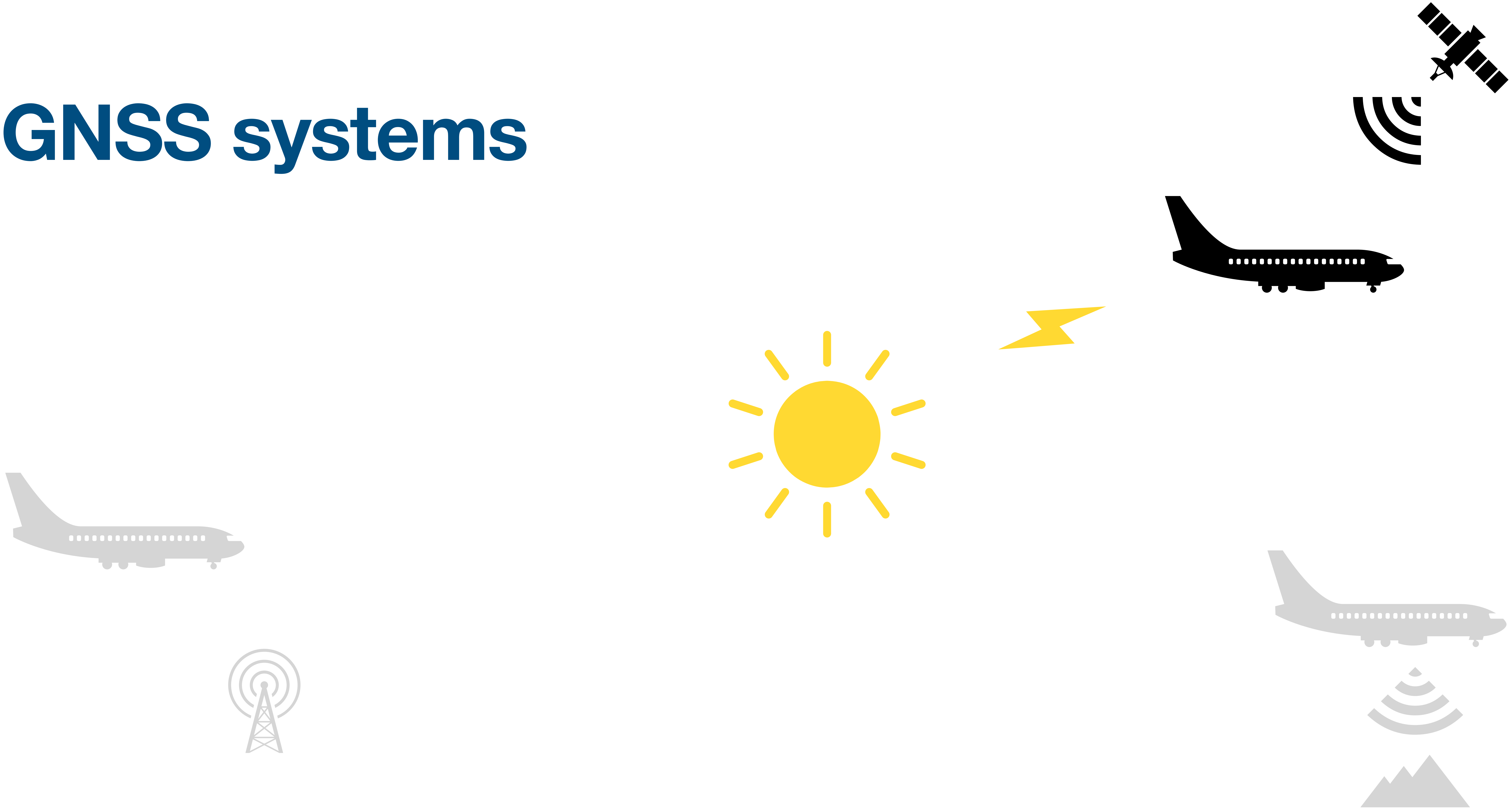
Forstyrrelser på Mode S
<<utsnitt - 2015Nov04_SunStrobe_ModeS>>

AVINOR FLYSIKRING

AVINOR

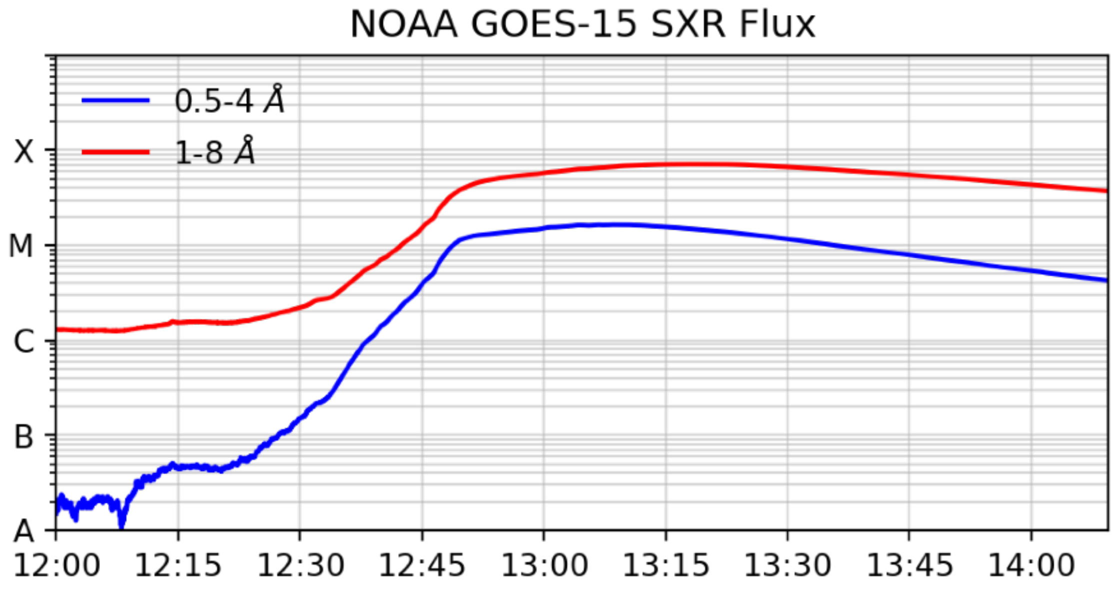
http://www.mn.uio.no/english/about/news-and-events/events/The%20Birkeland%20Anniversary/andreas-d-skjervold_150617.pdf

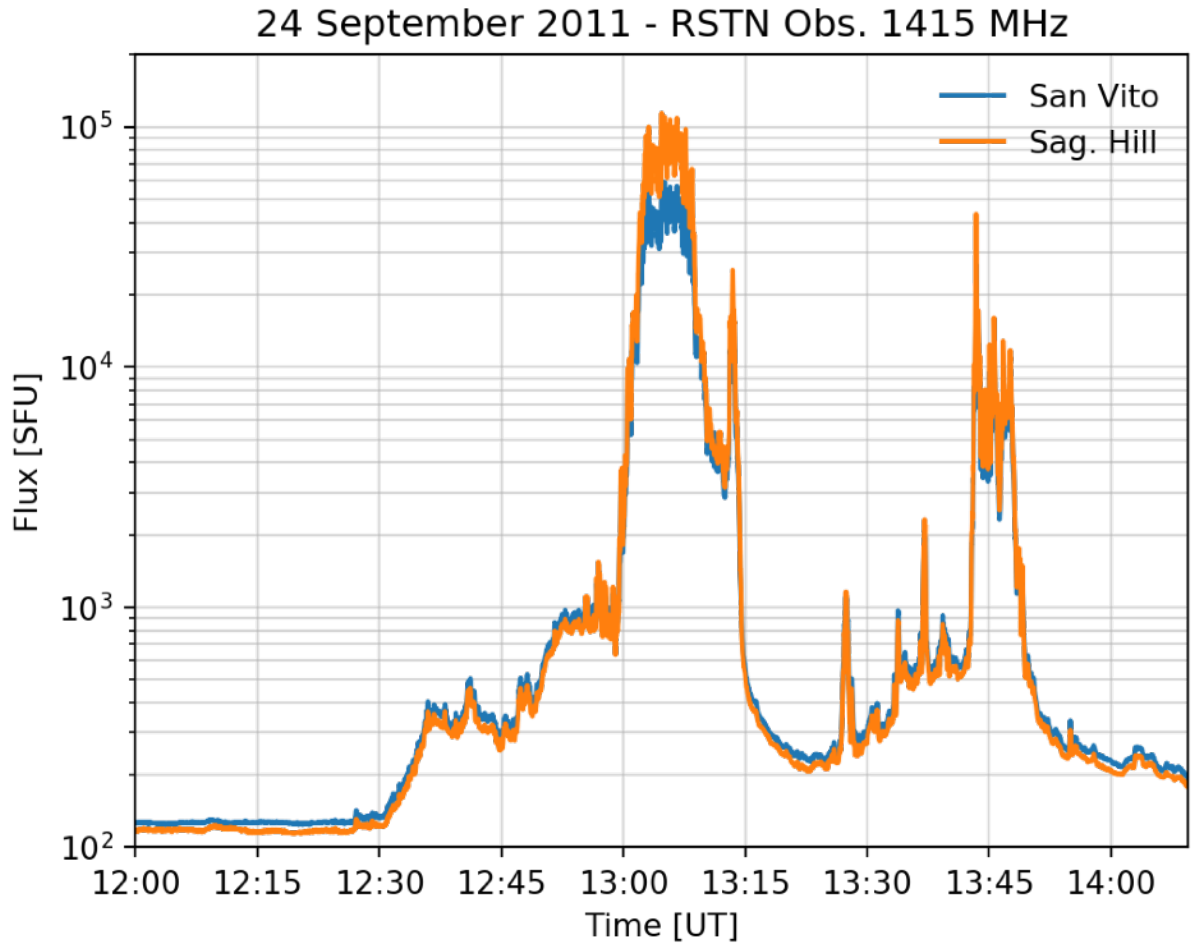
GNSS systems



Other services

GNSS





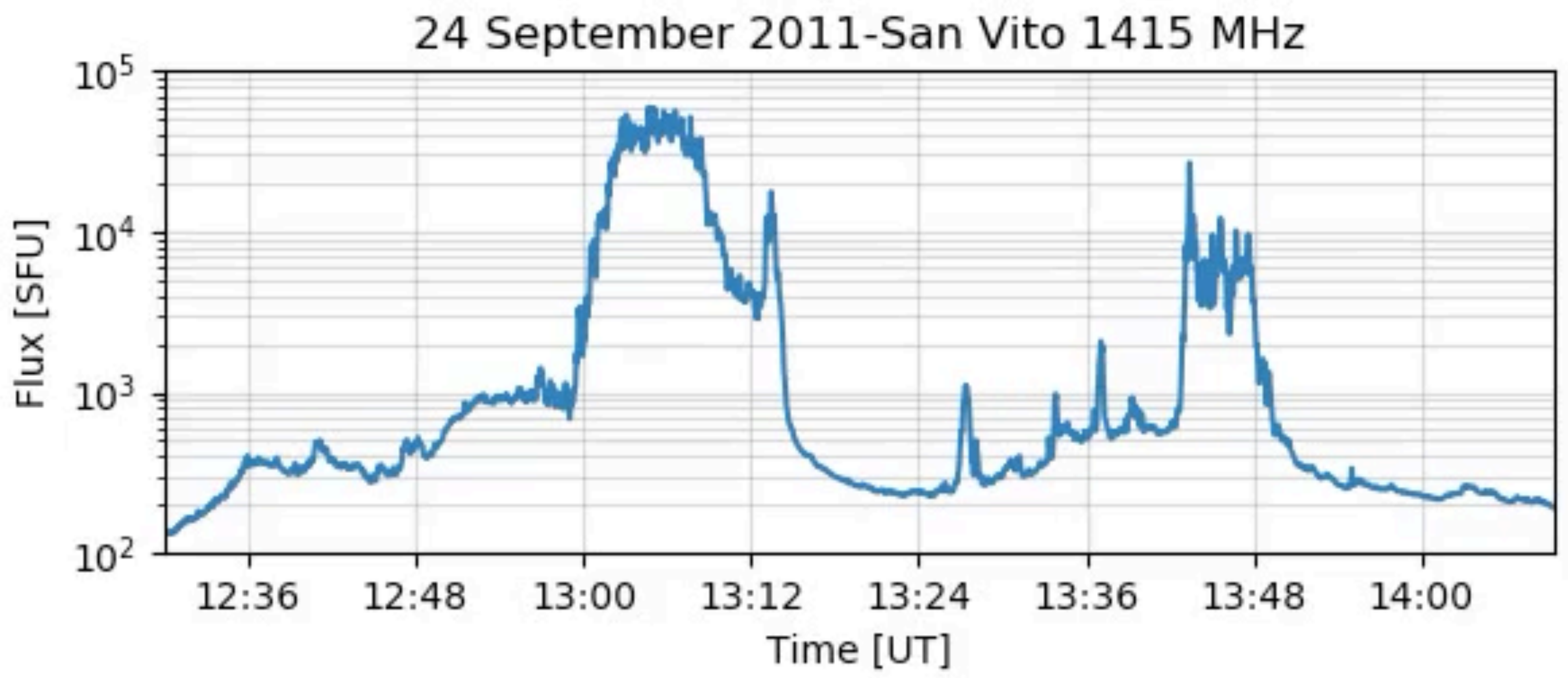
- M7.1 flare, max @ 13:20 UT
- AR 11302, Ekc, βγ

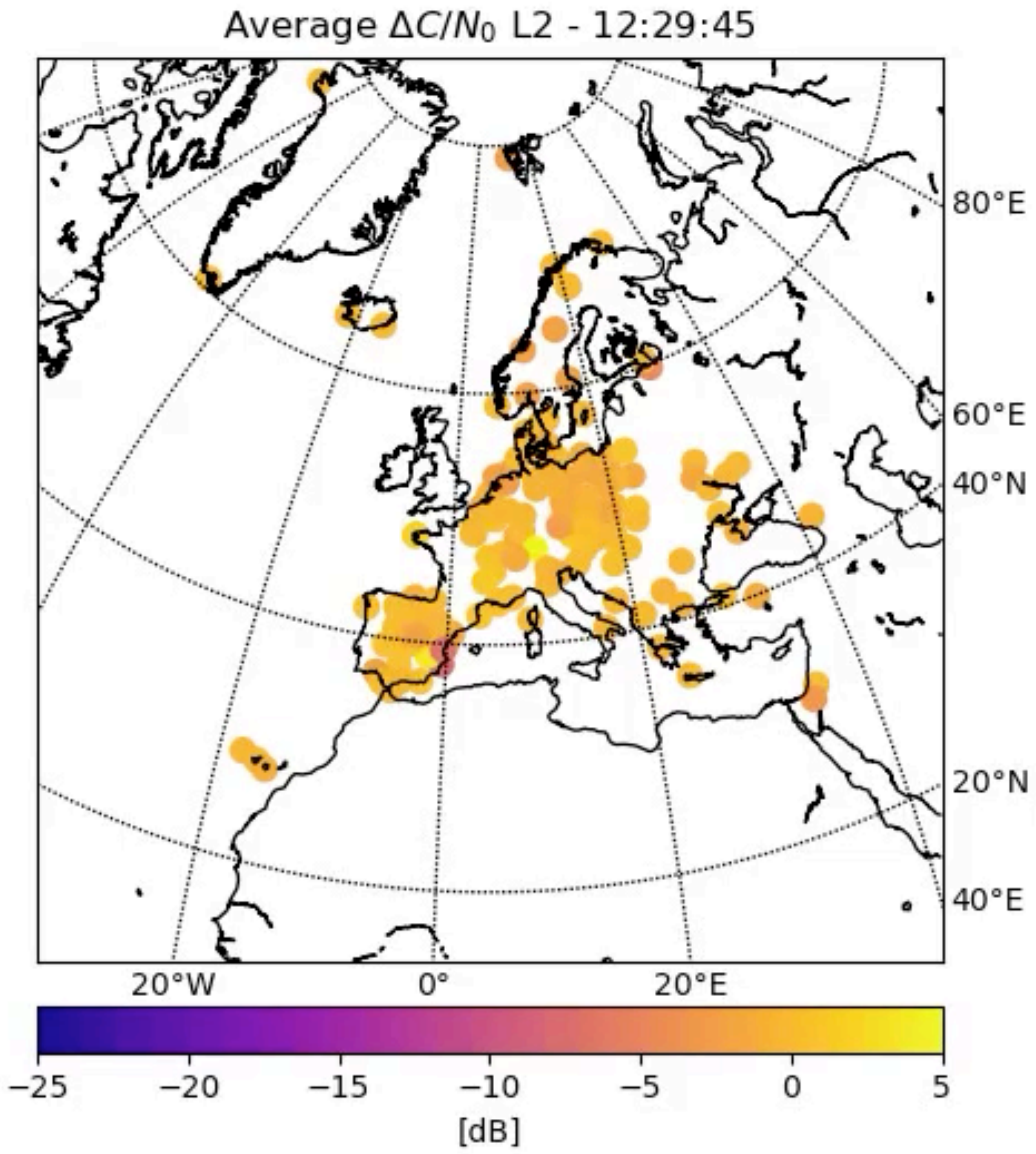
★110000 SFU @13:02 UT [Sag. Hill]

★60000 SFU [San Vito]

- Dm type IV burst (Bleien, Ondrejov)

C/N0 degradation

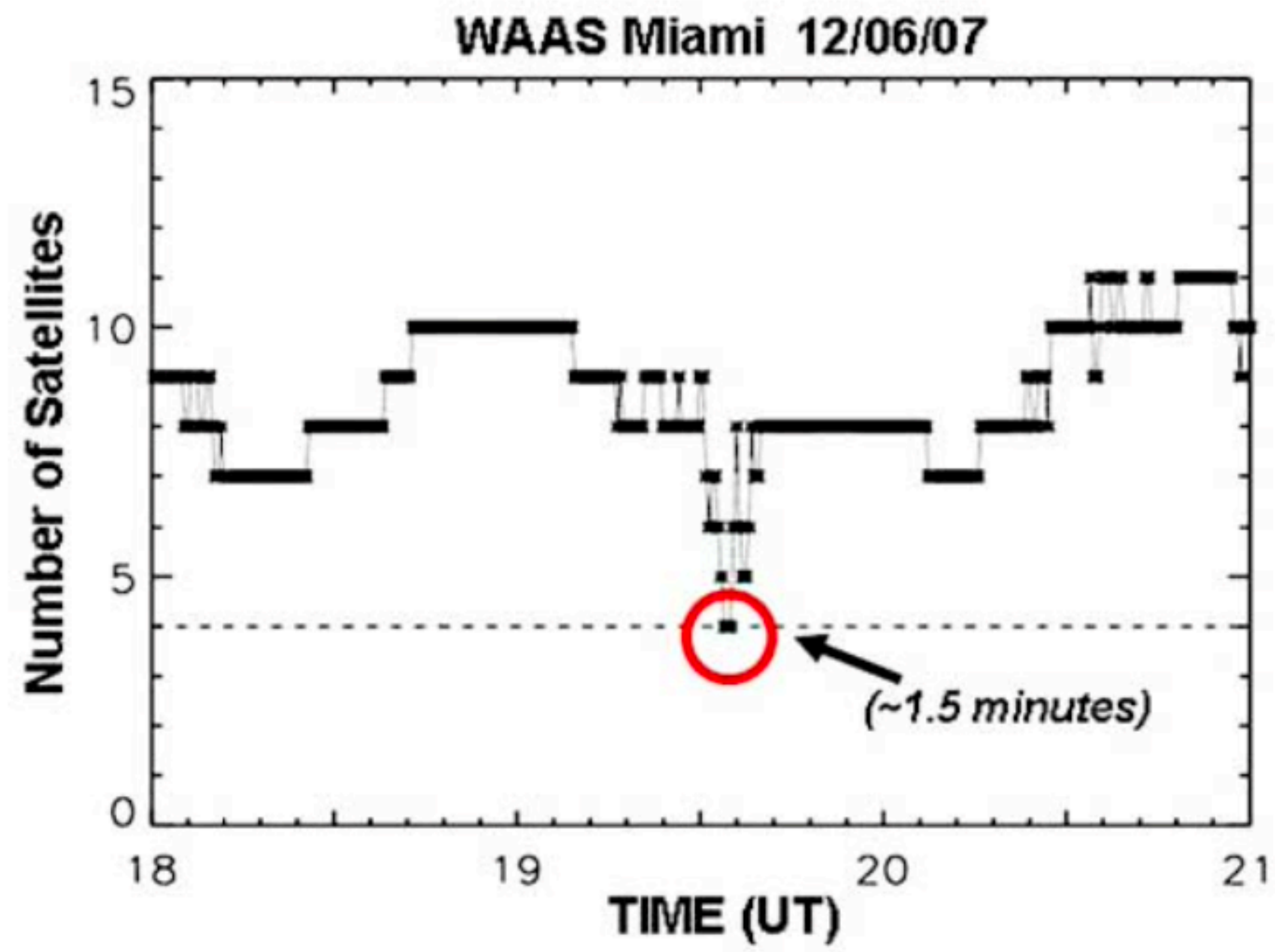


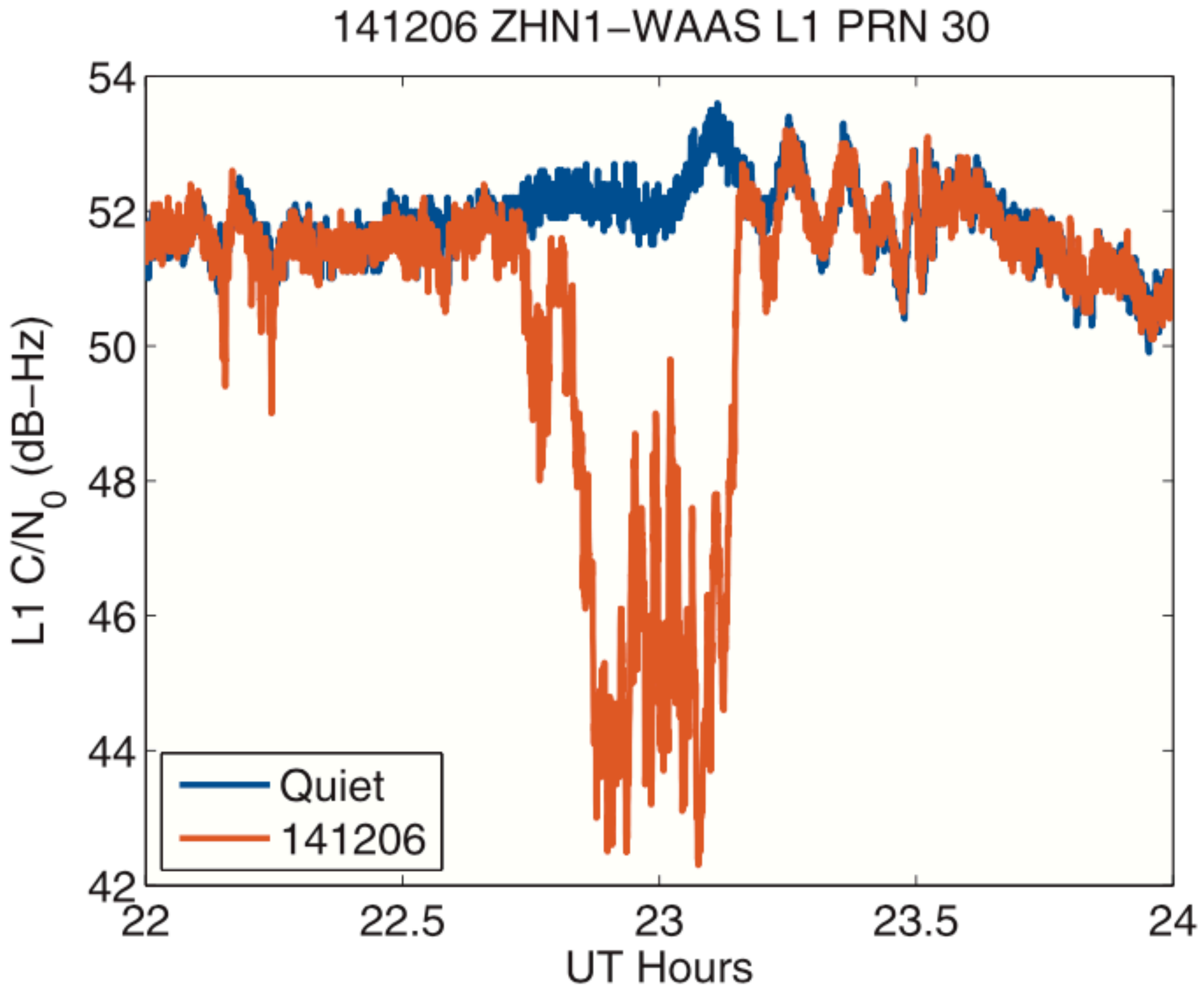


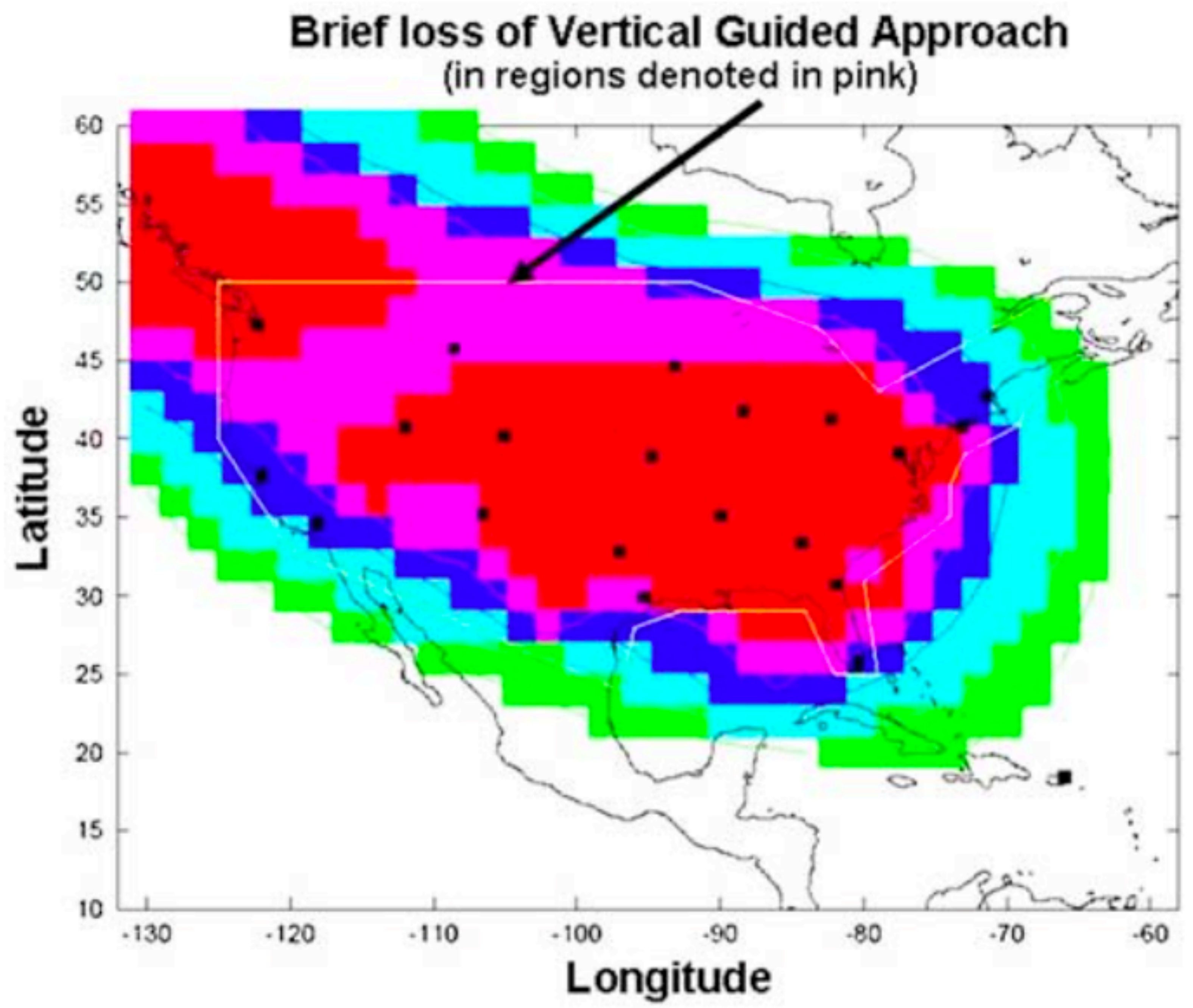
Impact on WAAS/EGNOS systems

December 6 2006 event

- X6 flare producing an intense SRB (type IV) at 1415 MHz (10^6 SFU - RHCP)

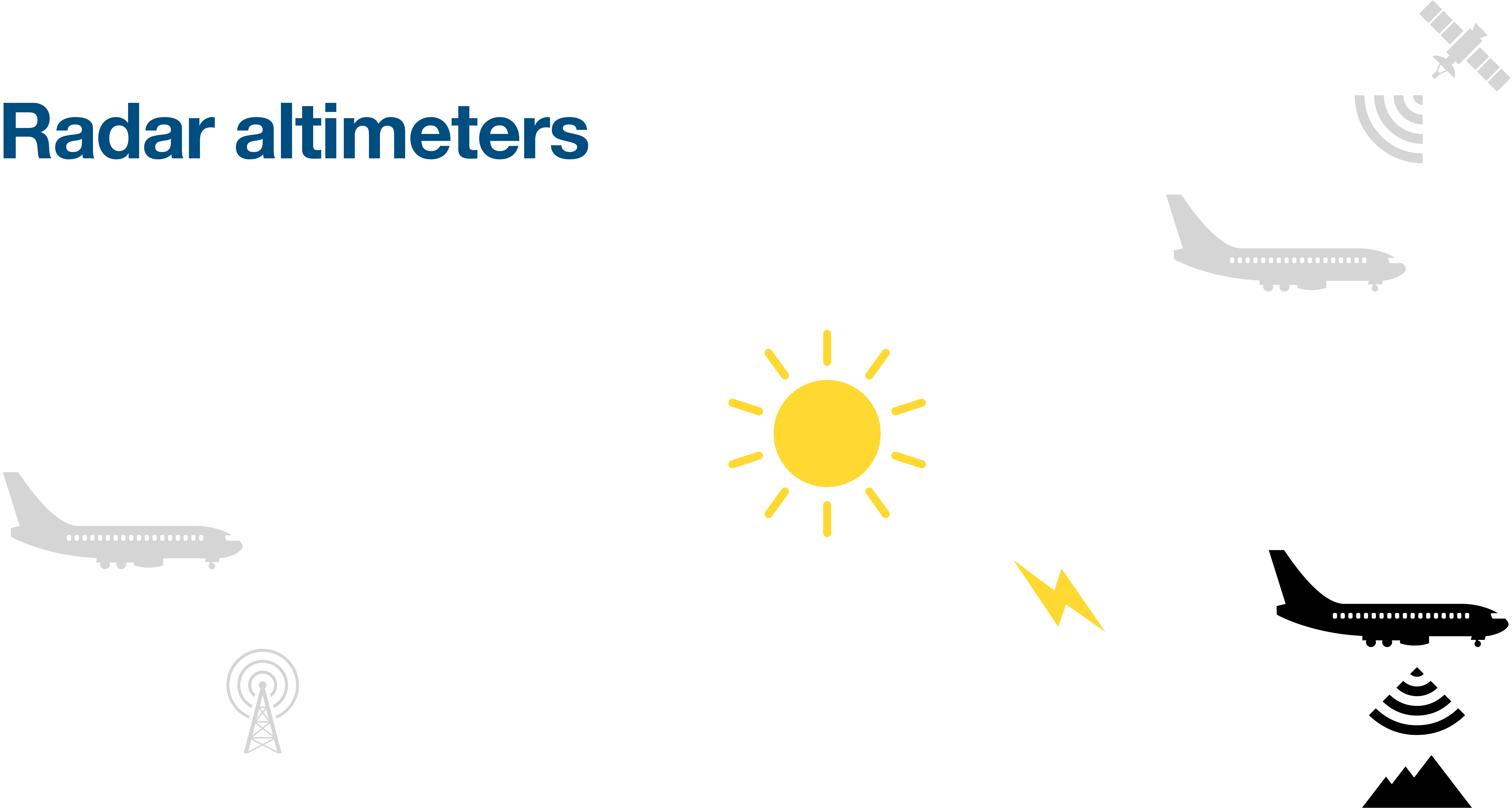






Cerruti et al., 2008

Radar altimeters

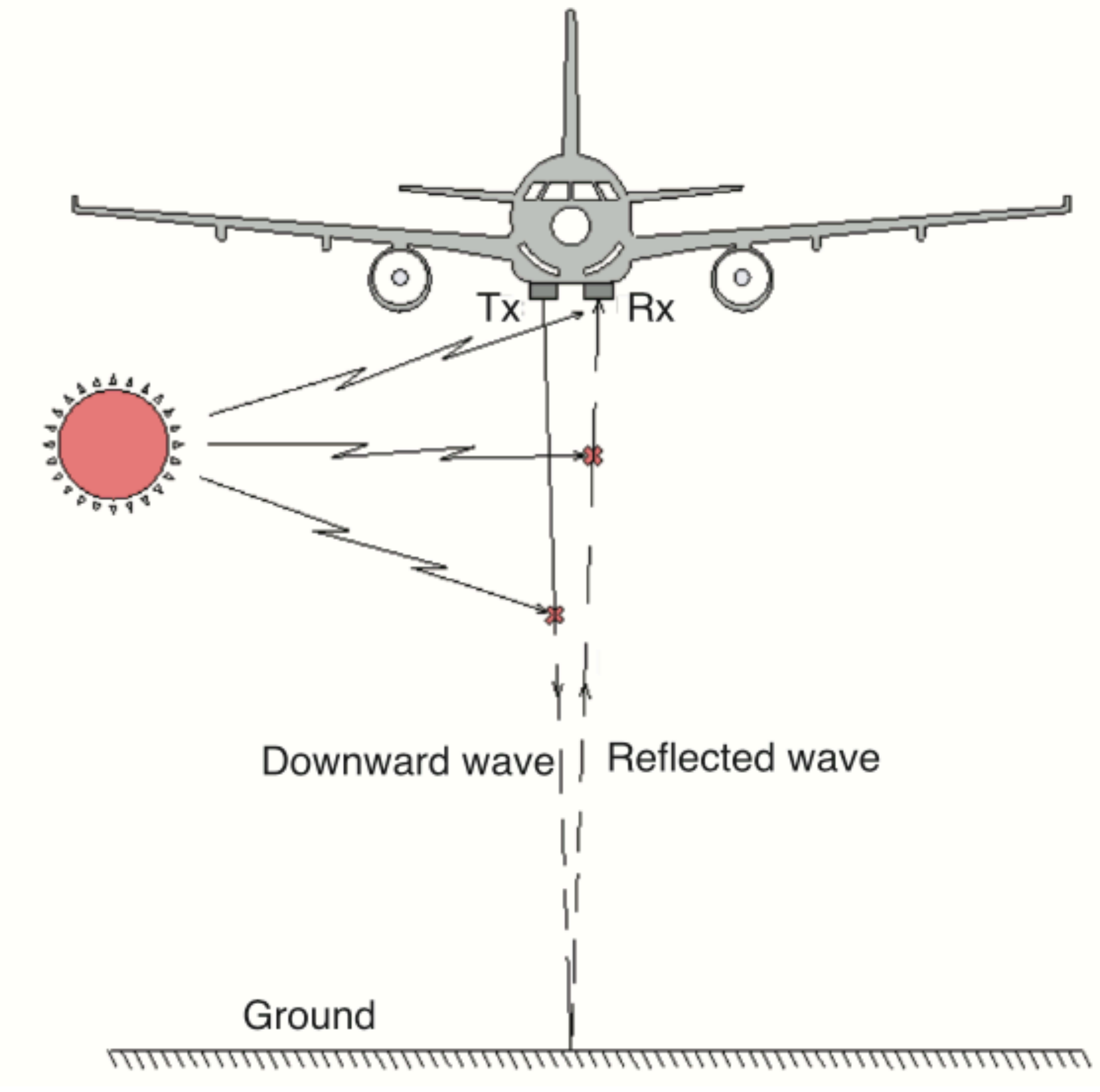


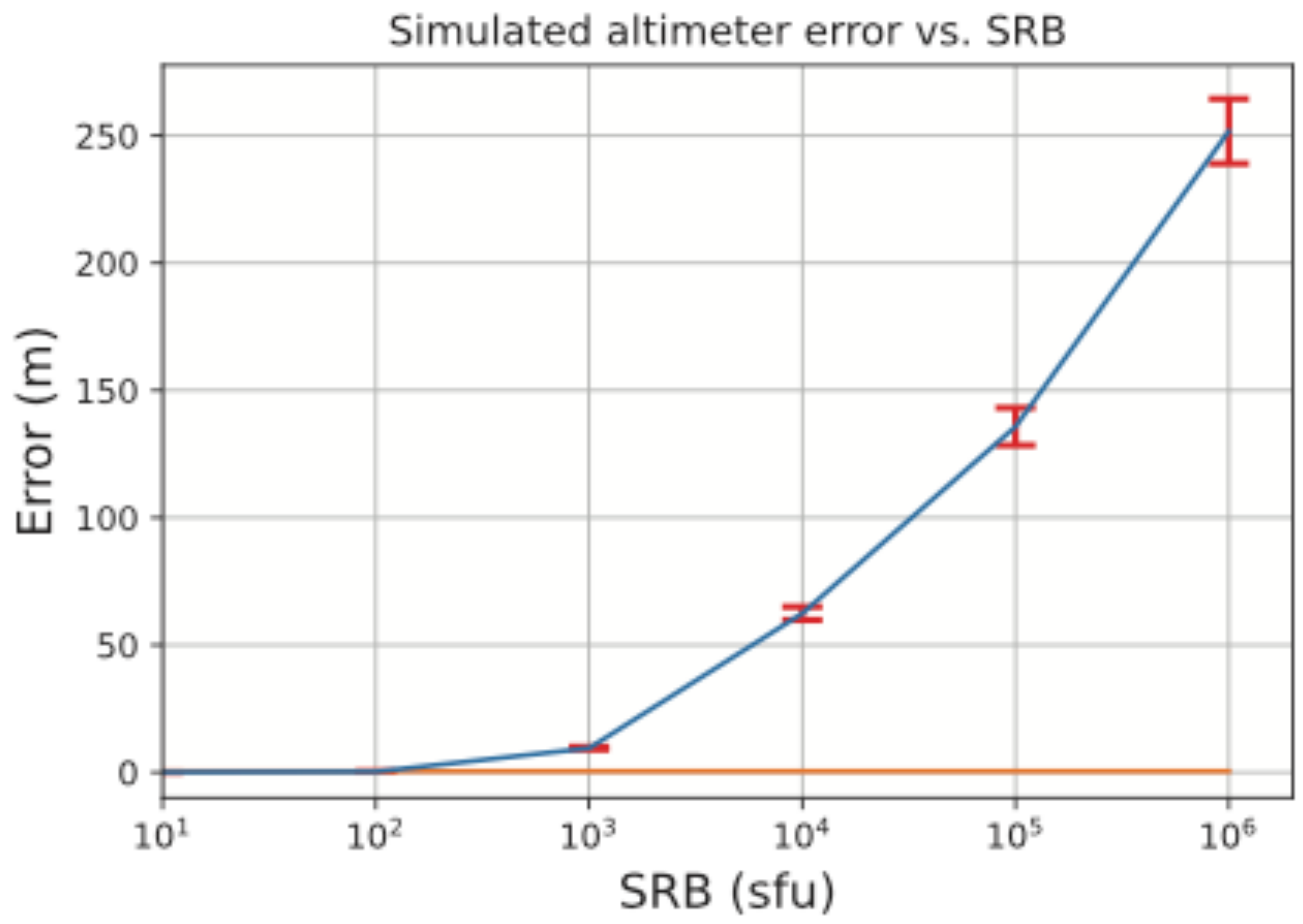
Radar altimeter

Estimated susceptibility

- Measurement of height Above Ground Level
- 4.2 - 4.4 GHz
- Devices on the plane belly

Mc Kee et al., 2023





In conclusion

- Long duration and intense radio bursts (type IV) are to be monitored
- ATC radar and GNSS (WAAS/EGNOS) systems used by the aviation industry are susceptible to interferences from Solar Radio Bursts
- Radar altimeters may be susceptible
- These systems may be degraded during critical parts of flights (landing, traffic around airports etc...)
- New generations systems show some robustness
- Awareness of operators and pilots is critical