Paper review: **“Exploring the potential of microwave diagnostics in SEP forecasting: The occurrence of SEP events”** by Zucca et al. 2017

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SWRL seminar

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Introduction – Solar Energetic Particles (SEPs)

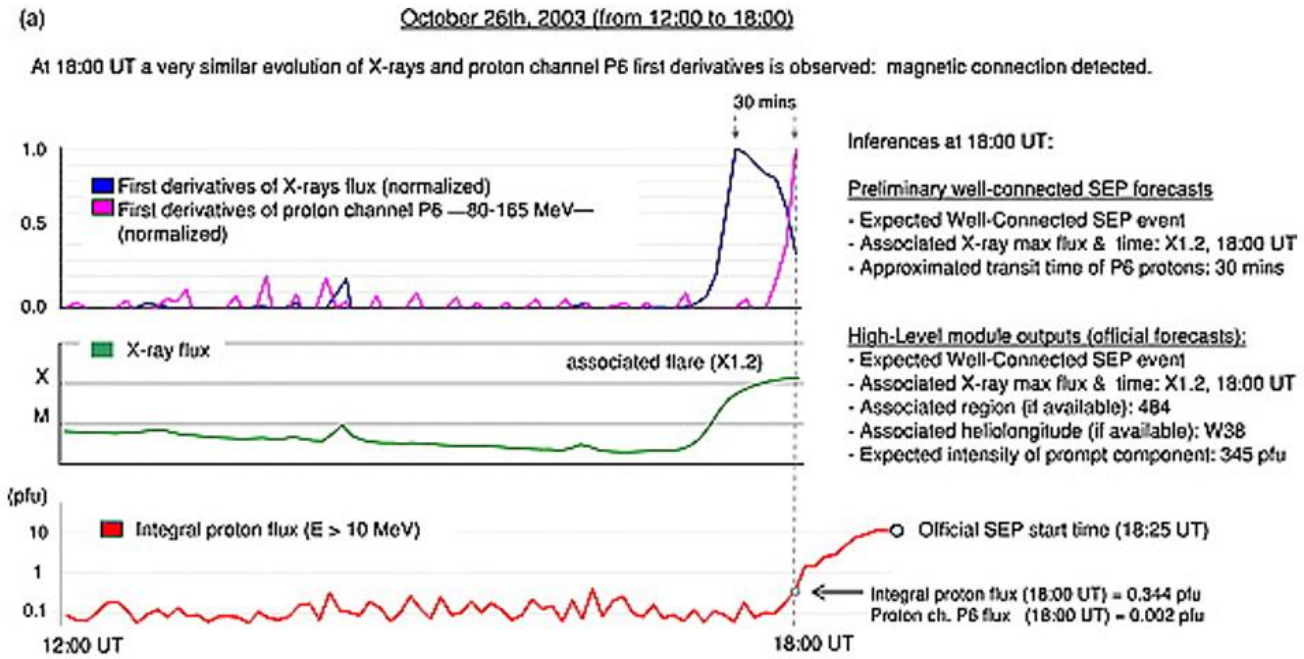
- High-energy protons, heavy ions, & electrons
  - Disturb/damage electronics onboard spacecrafts
  - Affect ionization of the Earth's atmosphere
  - Harms to astronauts
- Accelerated by flares and/or CMEs
- As of today, the only practical way to "predict" SEPs is to use the information of the eruptive event itself – i.e., particle signature

Introduction – some current forecasting systems

- Empirical
  - USAF & NOAA SWPC: Location, magnitude, & time evolution of the SXR flares
  - COMESEP
- Physics-based (shock theory)
  - SOLPENCO: Database of pre-calculated flux profiles + various IP scenarios
  - SPARX: Pre-generated model runs + injection location
- In-situ particle-based
  - RELEASE: In-situ energetic electrons observation
  - **UMASEP: SXR emission, time derivative, & in-situ proton observation**

UMASEP scheme

- "Well-connected" event prediction
  - Forecast trigger: >C4 flare, a **persistent** correlation between the sequence of $\frac{d}{dt}$(SXR flux) and $\frac{d}{dt}$(proton flux) in at least one GOES channel

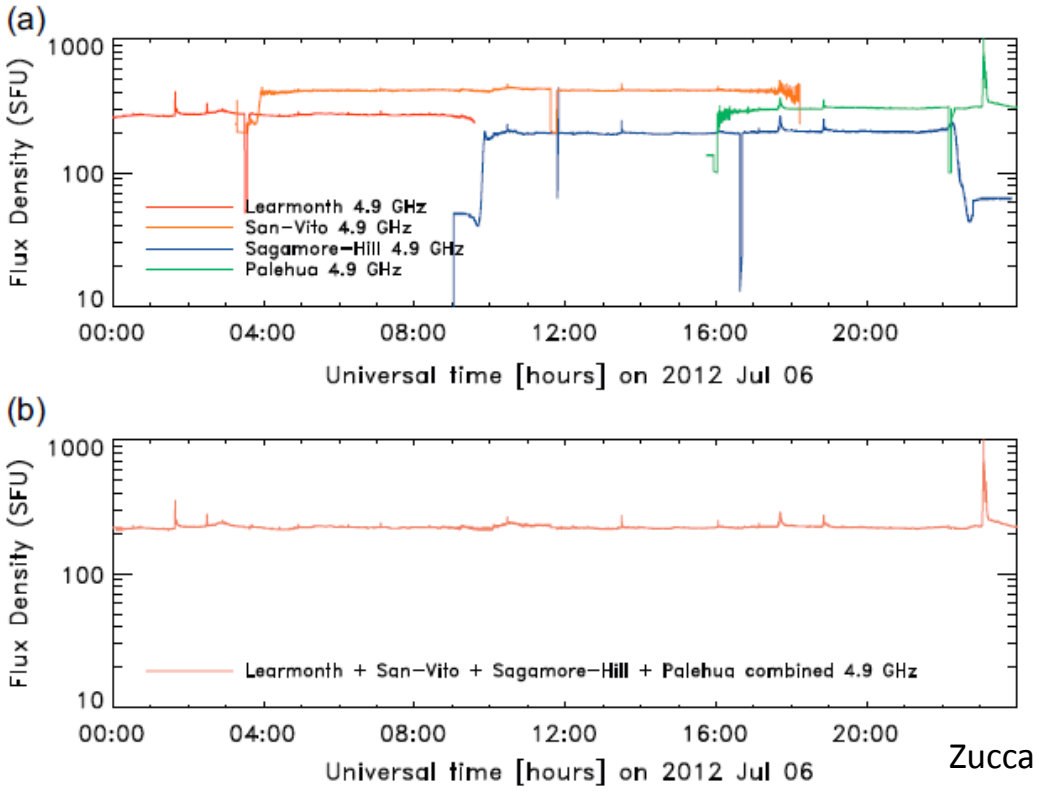


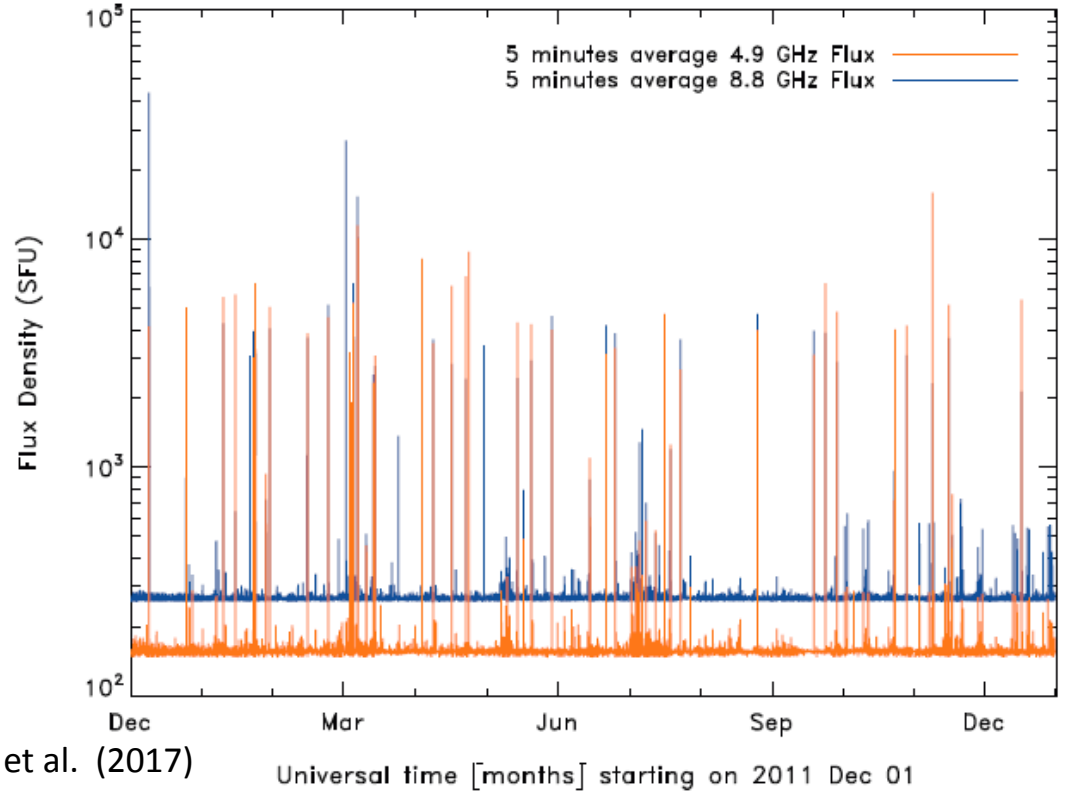
- It also predicts >10 MeV integral proton flux using an empirical function optimized by SEPs in solar cycles 22 and 23

Nunez (2011)

UMASEP scheme with MW

- Replace $\frac{d}{dt}$(SXR flux) by MW time profile! (Neupert effect)
- Use 5 & 9 GHz measurements from RSTN & NoRP
- Optimize probability of detection & false alarm rate during Dec. 2011 – Dec. 2012



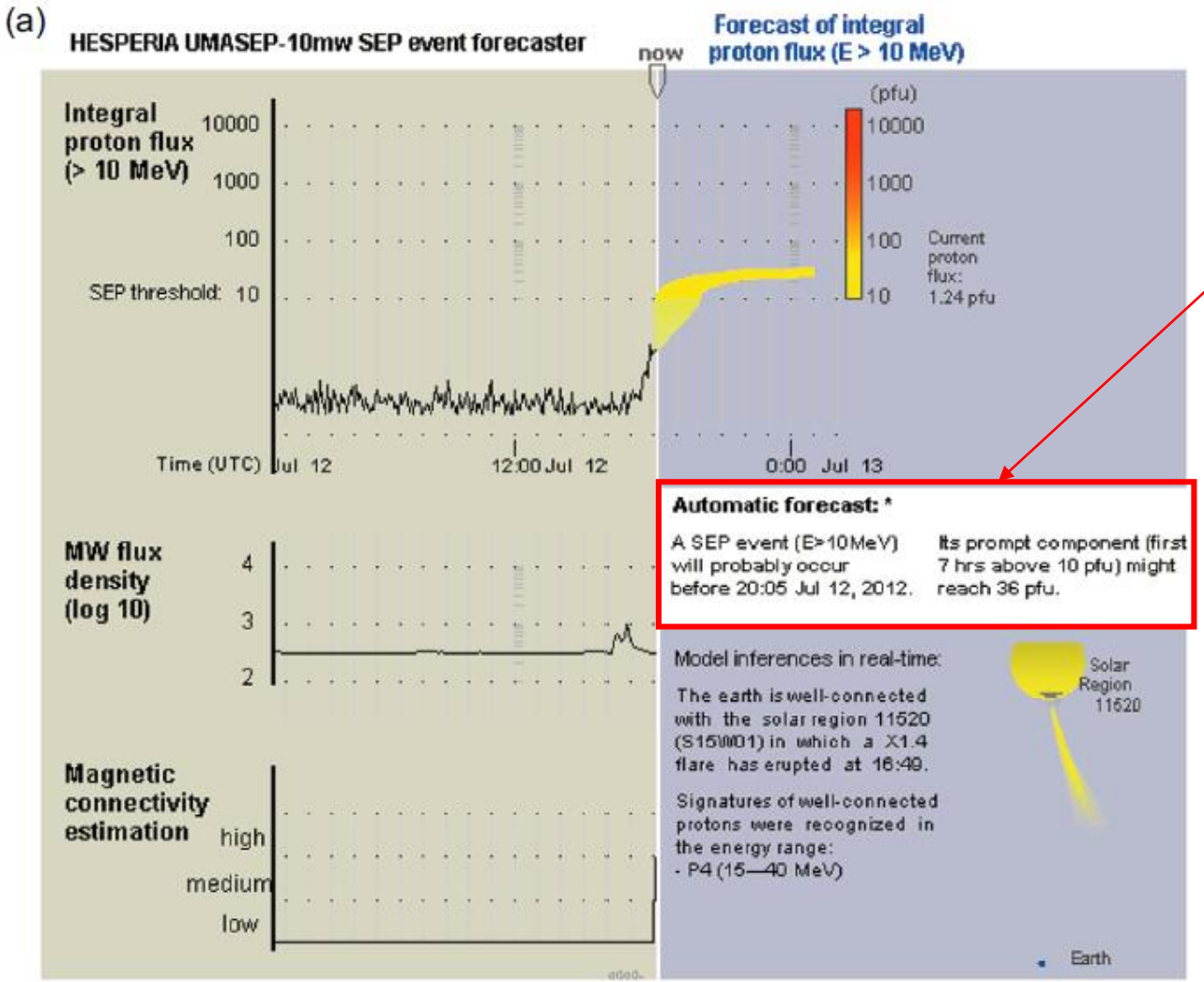


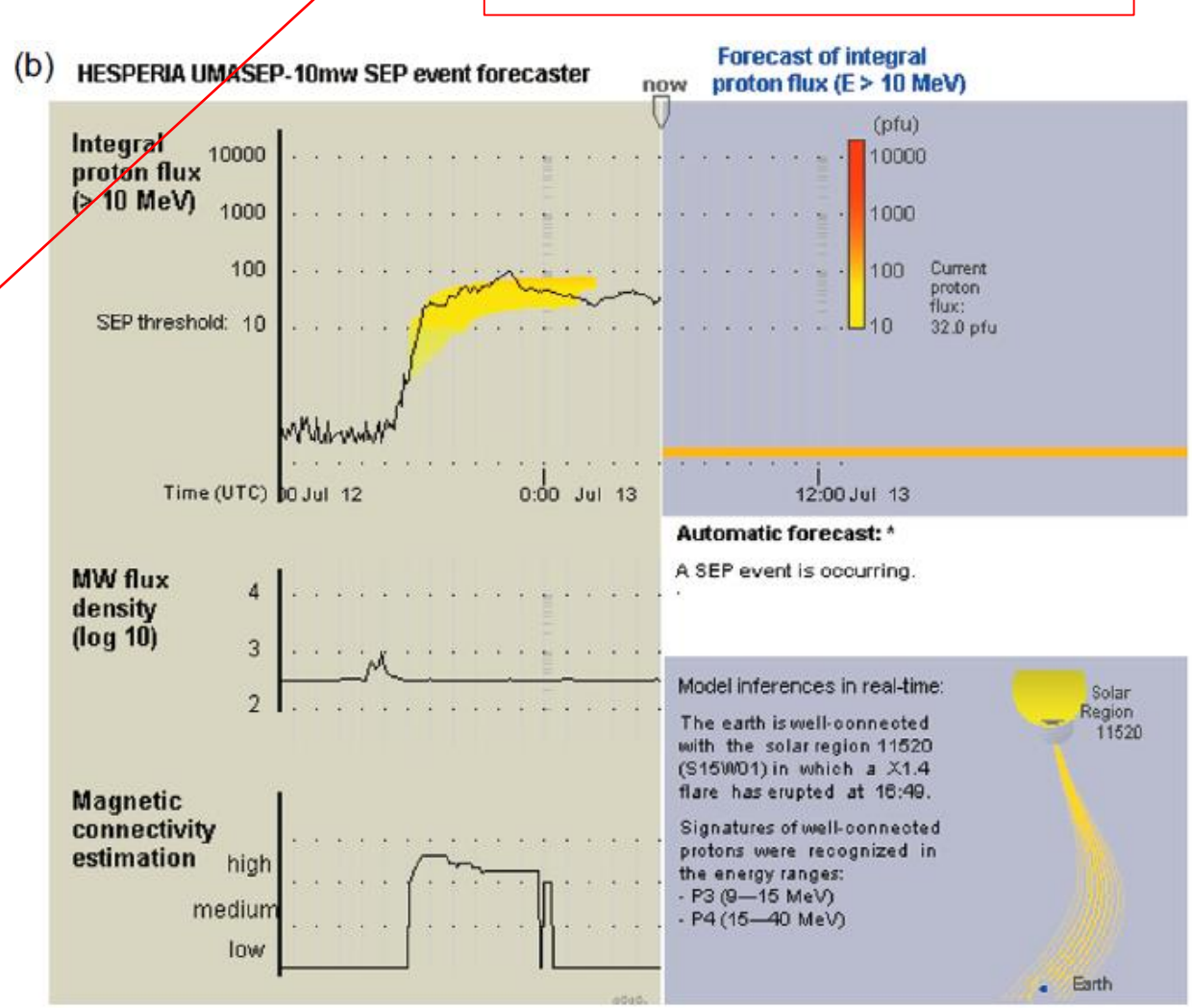
Zucca et al. (2017)

Sample result of UMASEP-10mw

18:05 SEP >10 MeV occurrence prediction (30-min warning)

Maximum integral flux estimate





Zucca et al. (2017)

Results

SEP		Flare		Warning time (WCP model)[1]			Result using WCP model[1]		
Start time	Peak time	GOES class	Location	5 GHz (min)	9 GHz (min)	SXR (min)	5 GHz	9 GHz	SXR
2012 Jan 23 05:30	Jan 23 03:59	M8	N28W36	50	50	45	Hit	Hit	Hit
2012 Jan 27 19:05	Jan 27 18:37	X1	N27W71	15	15	15	Hit	Hit	Hit
2012 Mar 07 05:10	Mar 07 00:24	X5	N17E15	25	25	70	Hit	Hit	Hit
2012 Mar 13 18:10	Mar 13 17:41	M7	N18W62	5	10	10	Hit	Hit	Hit
2012 May 17 02:10	May 17 01:47	M5	N12W89	5	5	5	Hit	Hit	Hit
2012 Jul 07 04:00	Jul 06 23:08	X1	S18W50				Miss	Miss	Miss[2]
2012 Jul 12 18:35	Jul 12 17:10	X1	S16W09	30	25	30	Hit	Hit	Hit
2012 Jul 17 17:15	Jul 17 17:15	M1	S17W75			10	Miss	Miss	Hit
2012 Sep 28 03:00	Sep 27 23:57	C3	N08W41	85	85		Hit	Hit	Miss

[1] WCP is the abbreviation of "well-connected prediction".
[2] The UMASEP-10's WCP model did not predict this event. Due to its gradual start, this event was predicted by UMASEP-10's poorly-connected event model.

- Same POD but no false alarm
- Slight increasein warning time

- SXR False-alarm: 2011-Dec-25 M-class flare was above C4 threshold, but MW fluxes did not hit threshold, and >10MeV level was too low to be considered as SEP event

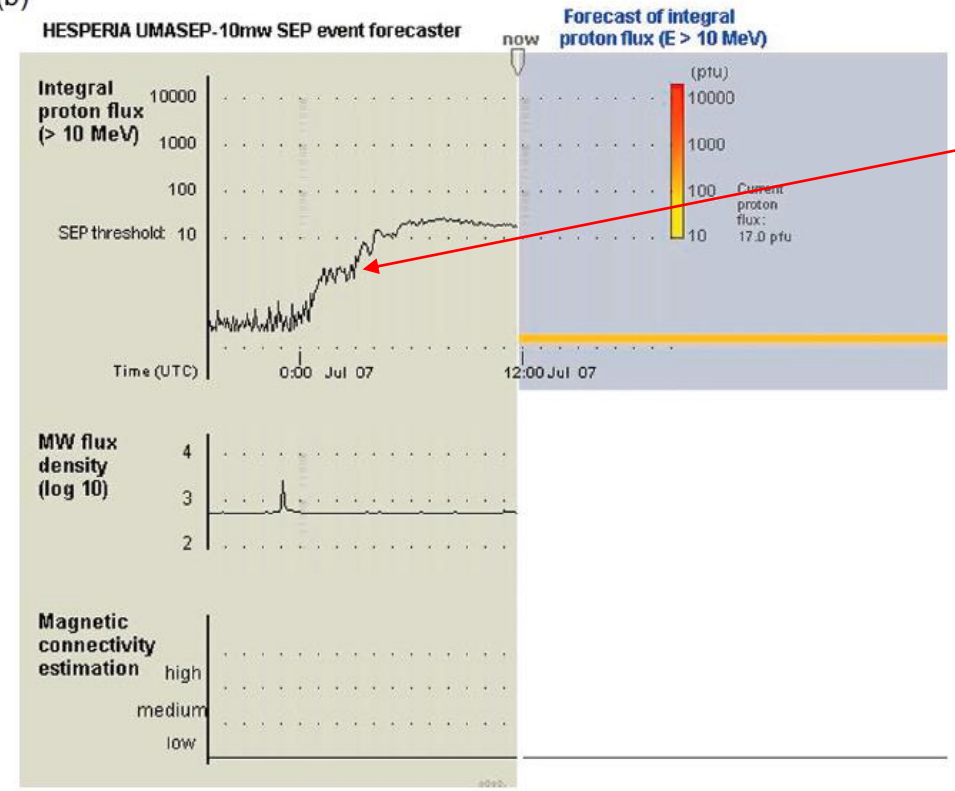
	UMASEP-10mw		UMASEP-10
	(5 GHz)	(9 GHz)	(SXR)
Probability of detection	77.8% (7/9)	77.8% (7/9)	77.8% (7/9)
False-alarm ratio	0% (0/7)	0% (0/7)	12.5% (1/8)
Average warning time	30.7 min	30.7 min	26.4 min

Zucca et al. (2017)

Analysis of missed events

SEP		Flare		Warning time (WCP model)[1]			Result using WCP model[1]		
Start time	Peak time	GOES class	Location	5 GHz (min)	9 GHz (min)	SXR (min)	5 GHz	9 GHz	SXR
2012 Jul 07 04:00	Jul 06 23:08	X1	S18W50				Miss	Miss	Miss[2]

(b)

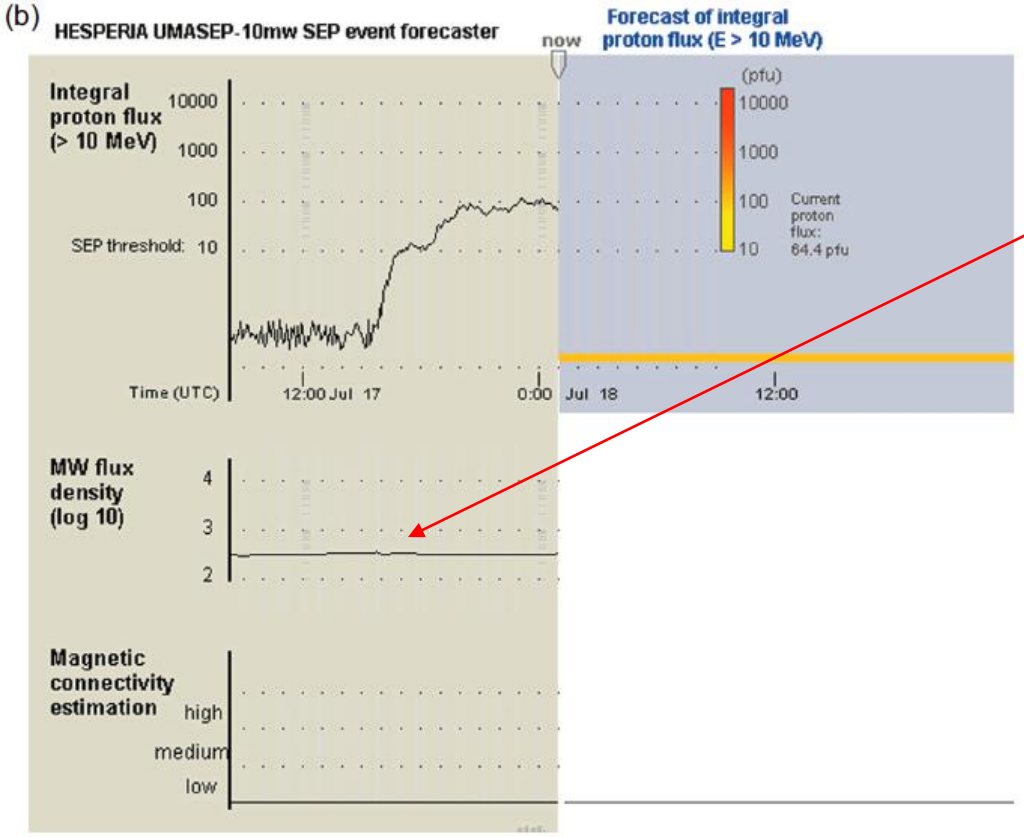


- The proton flux at GOES rose too slowly & noisy, so it was not correlated well with neither $\frac{d}{dt}$(SXR) nor MW (which were both impulsive)

Zucca et al. (2017)

Analysis of missed events

SEP		Flare		Warning time (WCP model)[1]			Result using WCP model[1]		
Start time	Peak time	GOES class	Location	5 GHz (min)	9 GHz (min)	SXR (min)	5 GHz	9 GHz	SXR
2012 Jul 17 17:15	Jul 17 17:15	M1	S17W75			10	Miss	Miss	Hit



- The MW flux increase was too small (~40 sfu) and the spectrum indicated thermal bremsstrahlung emission -> did not correlate with proton flux increase

Zucca et al. (2017)

Analysis of missed events

SEP		Flare		Warning time (WCP model)[1]			Result using WCP model[1]		
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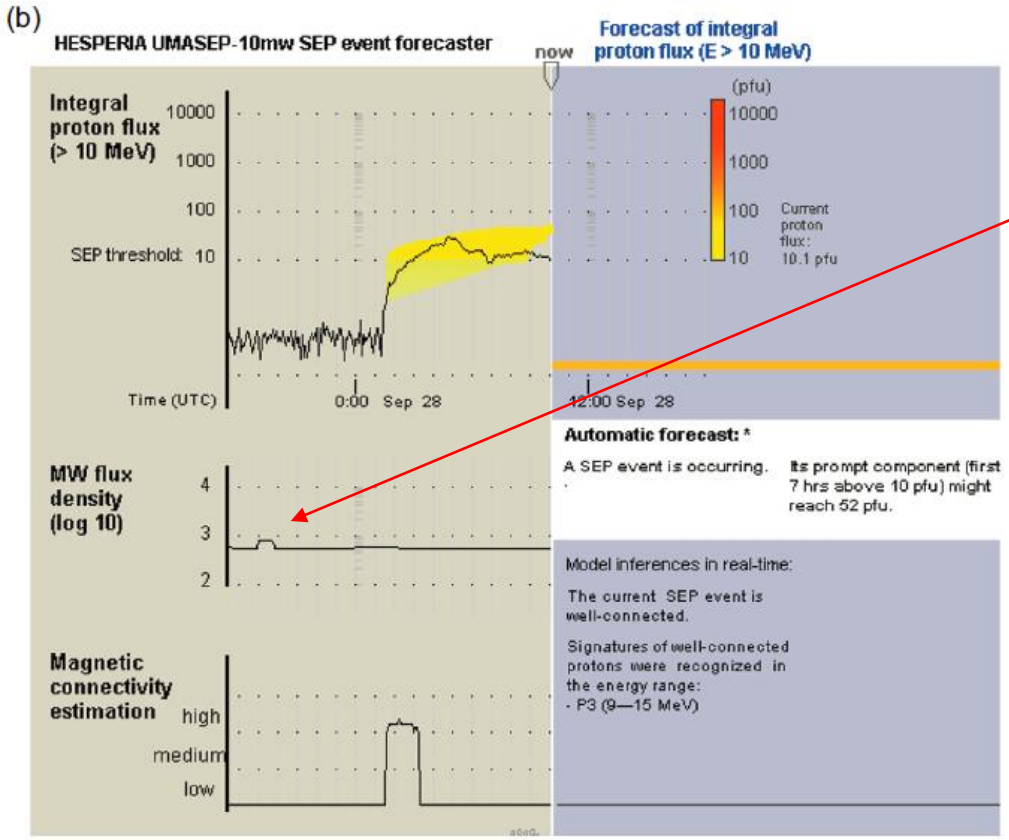
2012 Sep 28 03:00	Sep 27 23:57	C3	N08W41	85	85		Hit	Hit	Miss



- The SXR class was below C4 threshold, but MW increase was fast enough (although very small & probably thermal bremsstrahlung) to be correlated with proton flux increase

Zucca et al. (2017)

South pole observing station (24-hr during summer)??

Summary & discussion

The radio observations exploited in the present work are carried out with rather simple patrol instruments, which monitor the whole-Sun flux density using parabolic antennas with a typical size of 1 m. Such data are presently not provided in real time, but there is no technical obstacle to do so. If a reliable calibration and stable and reliable antenna operations can be achieved, microwave patrol observations will be a significant addition to our ability to predict the occurrence of SEP events. As attractive as microwave observations may be, they

Zucca et al. (2017)

- MW-based scheme's POD was the same, but no false-alarm
- MW-based scheme seems to fail when the emission is thermal bremsstrahlung, but can be successful if it rises fast enough
- Spurious fluctuations due to instruments can be potential problems: need better-controlled operation for automated prediction

- SEP mechanism/prediction research using electrons detected by EOVSA on the Sun vs. 1AU in-situ measurement?
  - There are some SEPs from C-class flares in the past, and they are mostly associated with CME shocks
  - SEPs are ion events, but electrons are more easily accelerated, so we can define SEPs by electrons – this will likely increase the size of database to study the SEP mechanisms ("electron-SEPs" should be detectable in smaller X-ray events)

  → Can we look at those smaller events that have MW bursts and electron enhancement at 1AU, and separate them by CME-associated and non-CME-associated (they will likely result in different electron properties at 1 AU), to learn something about SEP shock acceleration?