NPL
National Physical Laboratory

Solar Particle Effects in Aircrew Dosimetry

Graeme Taylor

Neutron Measurement Workshop

26th October 2006

Presentation Overview

- Overview of aircrew exposure to cosmic radiation
- NPL's involvement in aircrew dosimetry
- The origins of solar particle events (SPEs)
- The dosimetry of SPEs
- NPL's involvement in measuring SPE doses

In-Flight Exposure to Radiation

Air crew average occupational exposure:

* Short haul: ~2 mSv/y
* Long haul: ~4 mSv/y

(average UK background: 2.2 mSv/y)

* Average nuclear worker: <1 mSv/y

Since May 2000 airlines in the EU must assess the radiation exposure of air crew

Air Crew Exposure Studies

CAA / MSSL / NPL / VAA

Collaborative Partnership 2000 - 2004

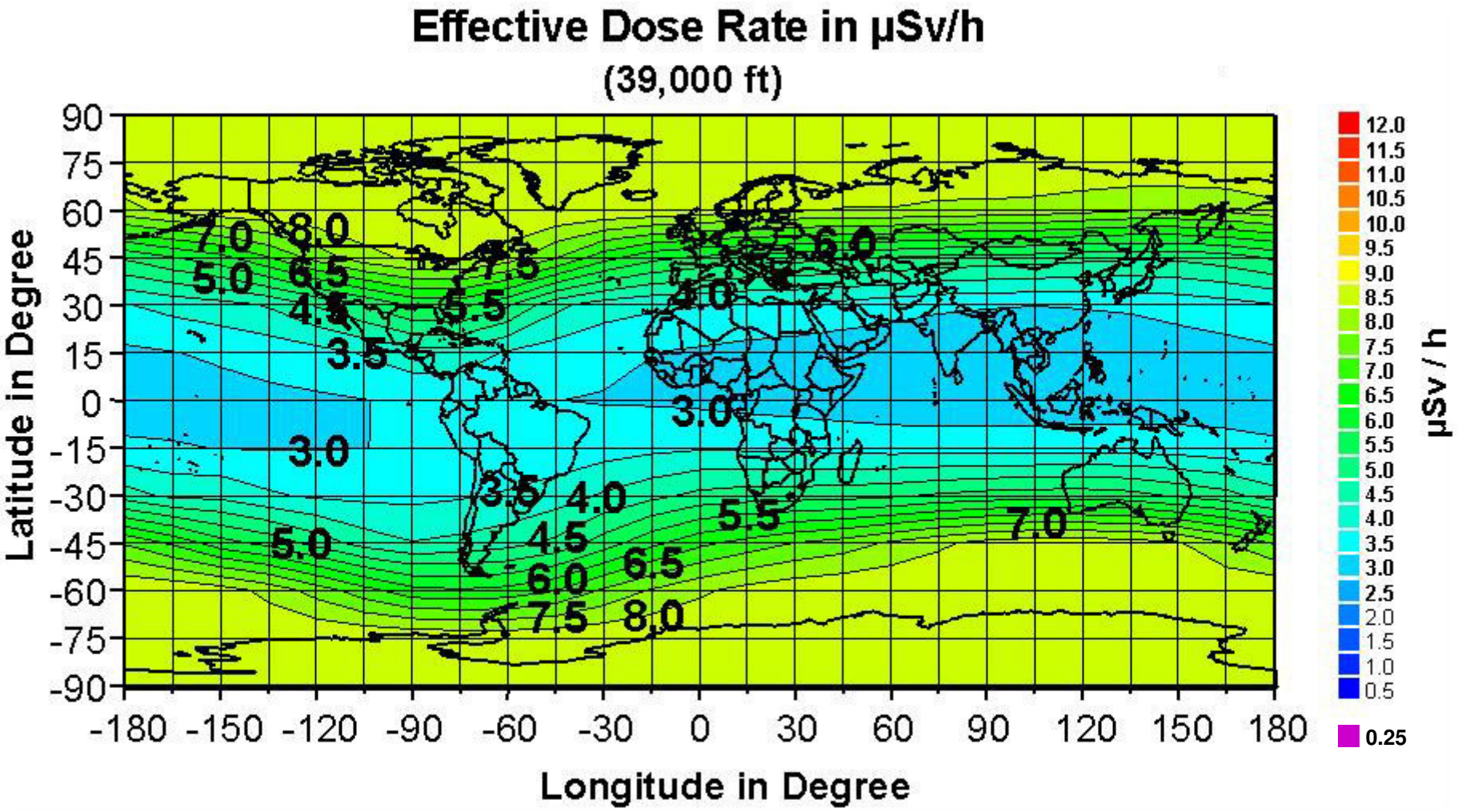
Objectives:

- Fly detectors (TEPCs) on commercial aircraft;
- Compare radiation dose measurements with predictions from computer codes used by airlines,
  e.g. CARI, EPCARD, SIEVERT

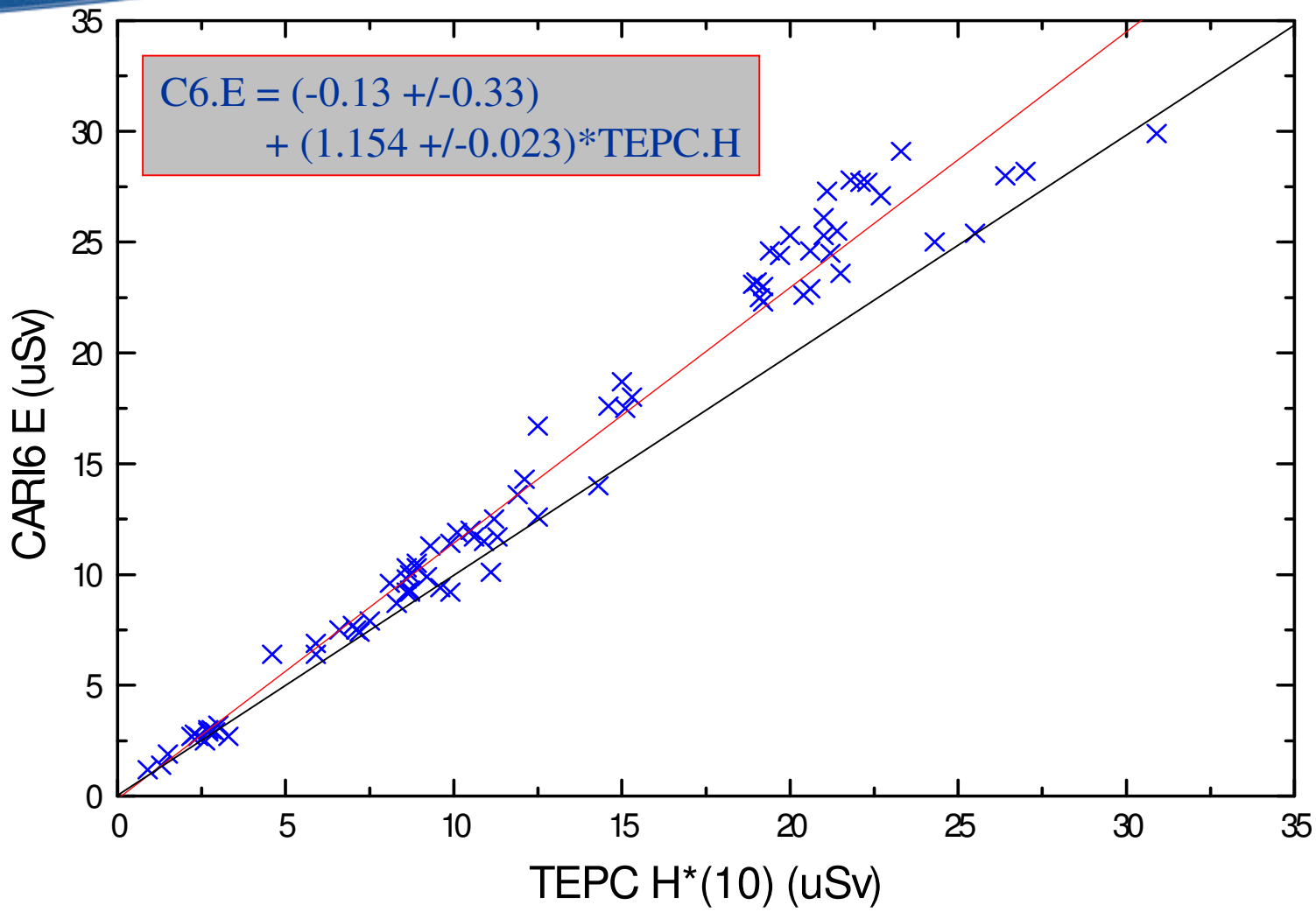
Global Dose Rate Map

The Space Weather Multimedia CD ROM

http://www.df5ai.net/ArticlesDL/SpaceWeatherCD/SpaceWeatherCD.html



Performance of CARI 6 vs TEPC Mmts for ANZ Routes



Comparison of Codes with TEPC Measurements

Flight	Flight Code	Ambient Dose Equivalent (μSv)			
		TEPC	CARI-6	SIEVERT	EPCARD
Lon-S/H	17180100	45.7	36.5	52.9	46.5
Lon-JFK	18190100	35.9	31.6	38.3	38.8
Lon-HK	14150700	37.8	33.4	47.3	39.7
HK-Lon	15160700	40.2	33.2	48.3	46.1
Lon-LA	16170700	40.2	42.6	53.6	51.5
LA-Lon	17170700	37.3	34.4	47.6	46.6

Accuracy
< 10%
10% - 20%
20% - 30%
>30%

The Solar Cycle and Atmospheric Radiation Levels

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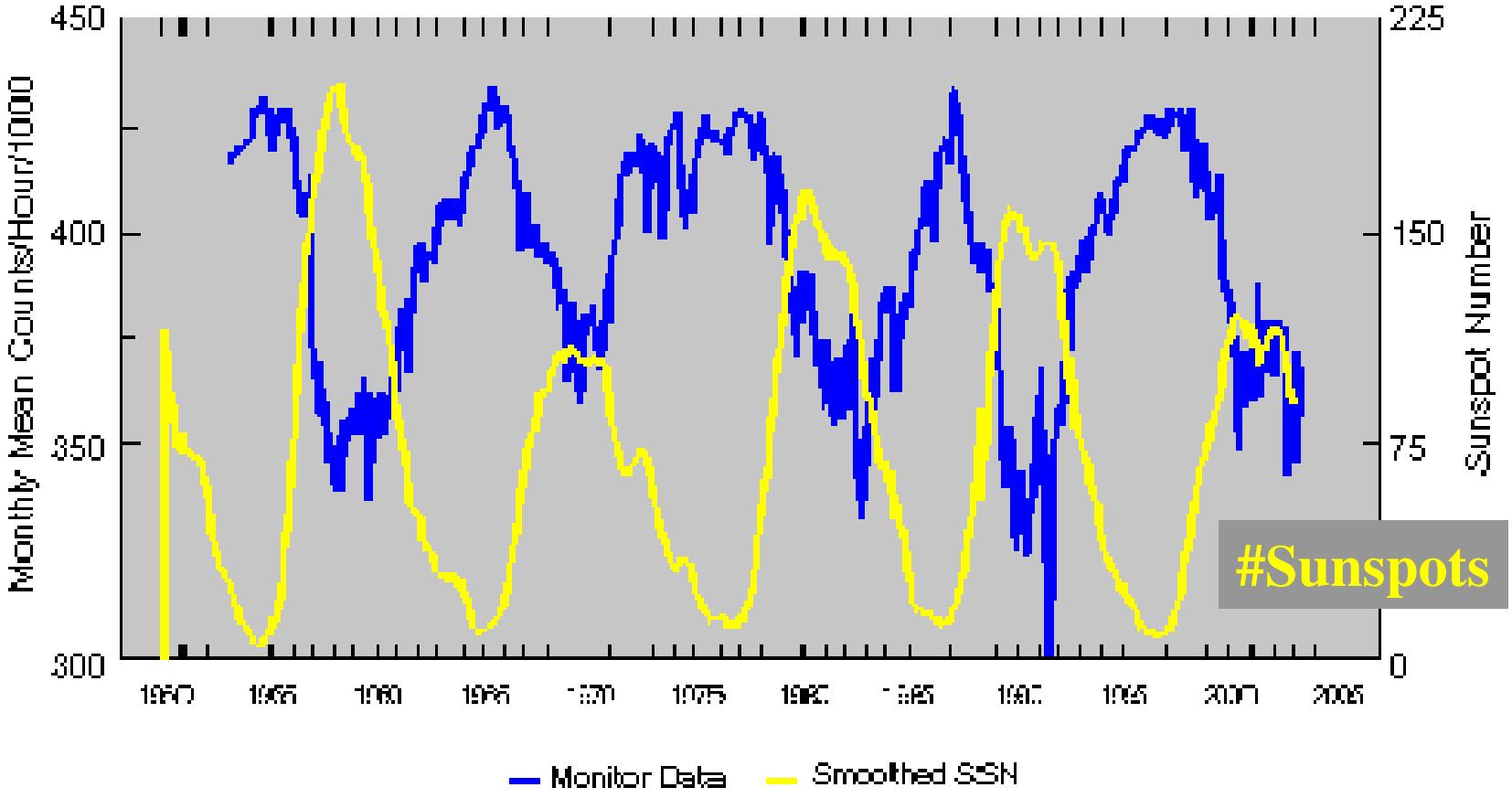
Ground-based Cosmic Ray Monitor



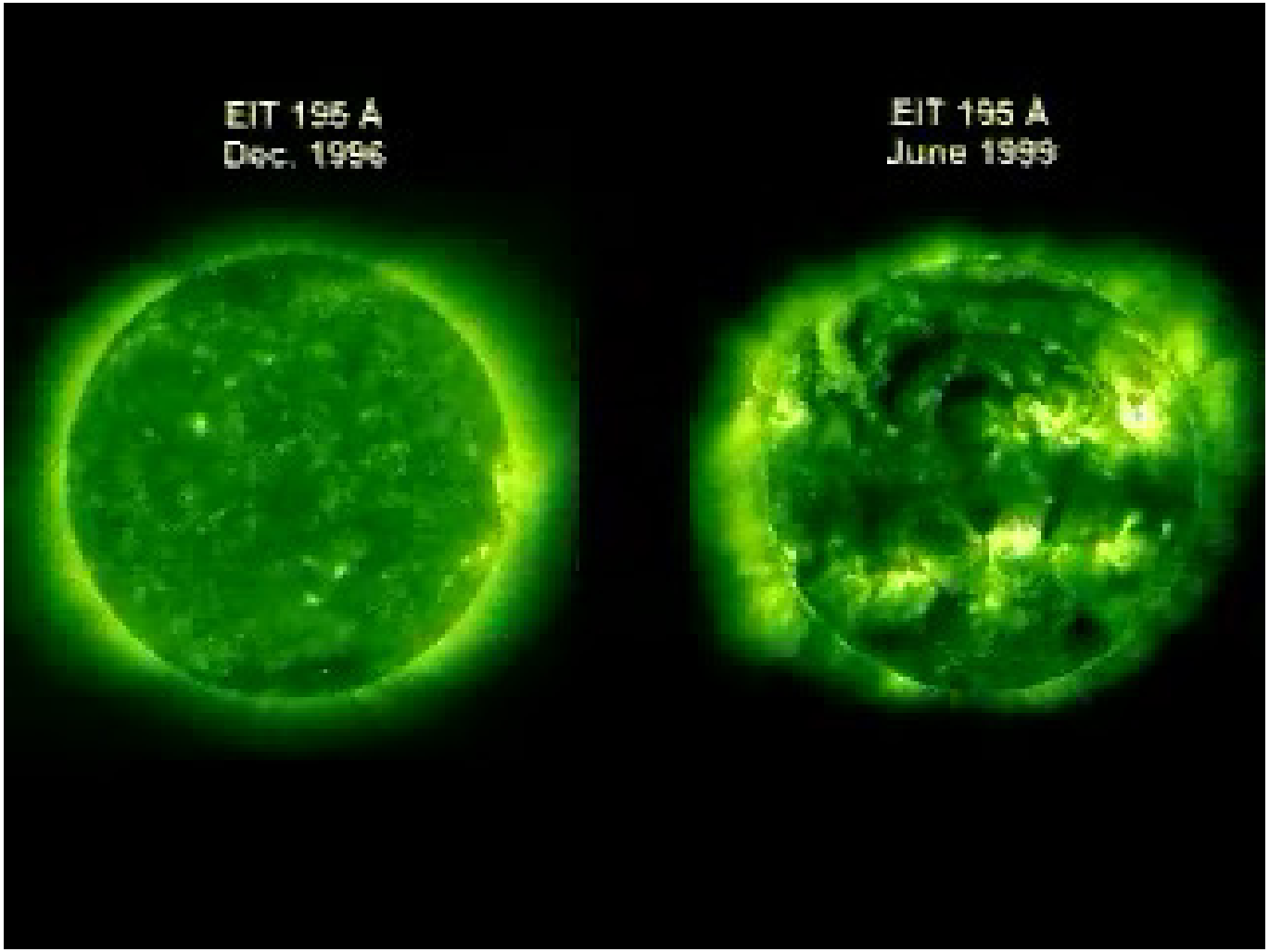
#Sunspots

The Sun's Magnetic Field

Source/Credits: *ESA / NASA*

‘Quiet’ Sun v ‘Active’ Sun

Source/Credits: *Solar & Heliospheric Observatory (SOHO).*
SOHO is a project of international cooperation between ESA and NASA



Bastille Day Event
July 14th 2000

Source/Credits: *Solar & Heliospheric Observatory (SOHO).*
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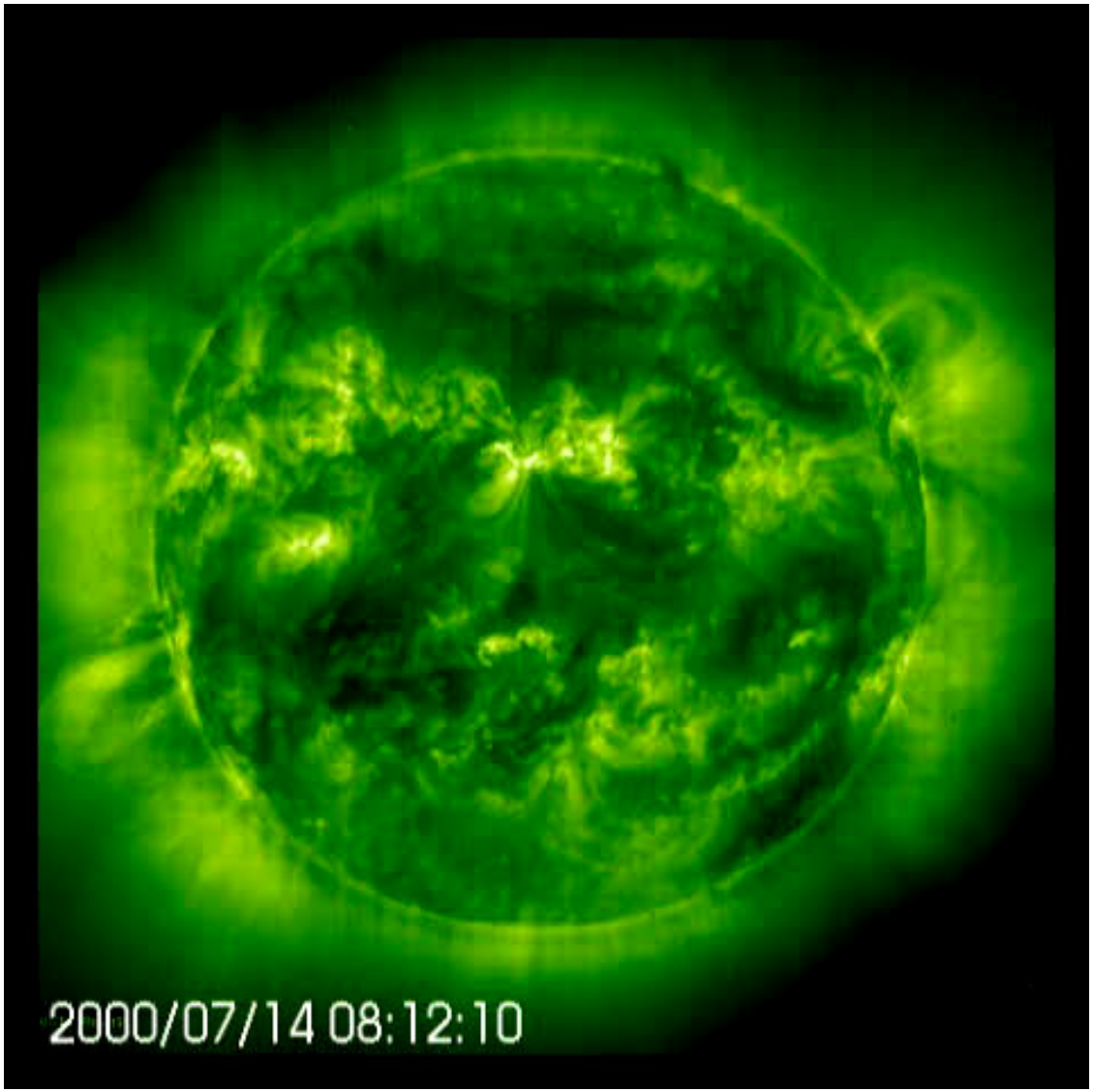
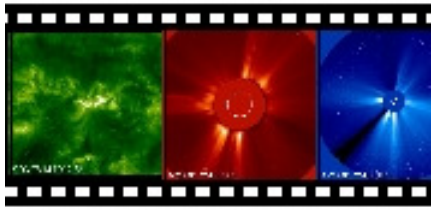
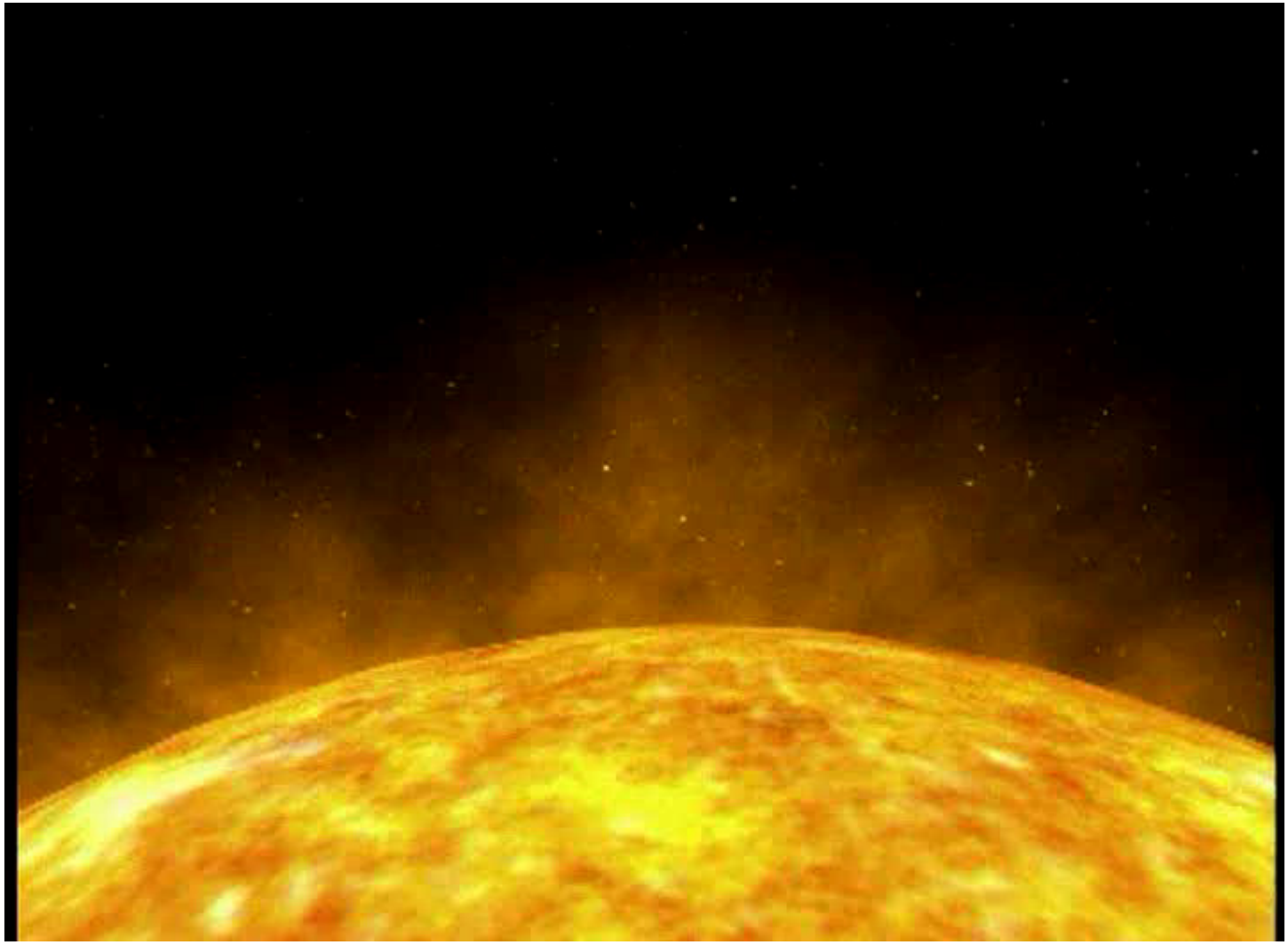


EIT (Soft X-rays) | LASCO C2 & C3 (White light)



Disruption of Earth's Magnetic Field

Source/Credits: *ESA / NASA*



Issues with CR Dose Predictions

Factors Underlying GCR Dose Prediction

- Galactic Cosmic Ray field is reasonably constant
- Modulating effects of Solar Activity reasonably well understood
- Plenty of measurements for comparison

Factors Underlying SPE Dose Prediction

- SPE fields vary widely
- Modulation effects of Solar Activity unpredictable
- Very few measurements for comparison

GCR v SPE Spectra

From: Advances in Space Research, Vol. 32, pp. 81-93, 2003.

CALCULATIONS AND OBSERVATIONS OF SOLAR PARTICLE ENHANCEMENTS TO THE RADIATION ENVIRONMENT AT AIRCRAFT ALTITUDES

C.S. Dyer, F. Lei, S. N. Clucas, D. F. Smart, M. A. Shea

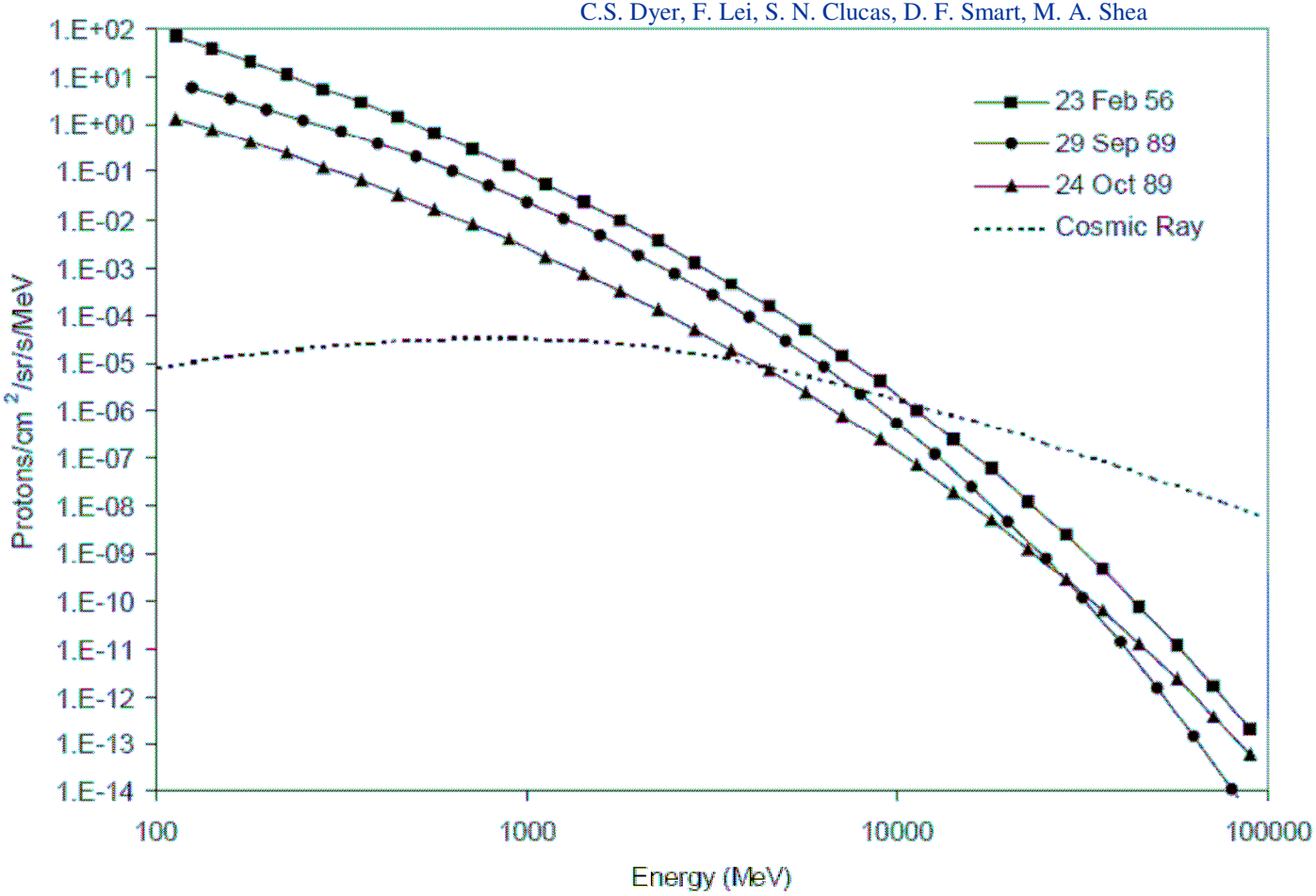


Fig. 2. Derived spectra of peak fluxes for the 3 solar proton events are compared with the solar maximum cosmic ray spectrum.

Time-Dependence of SPE Spectra

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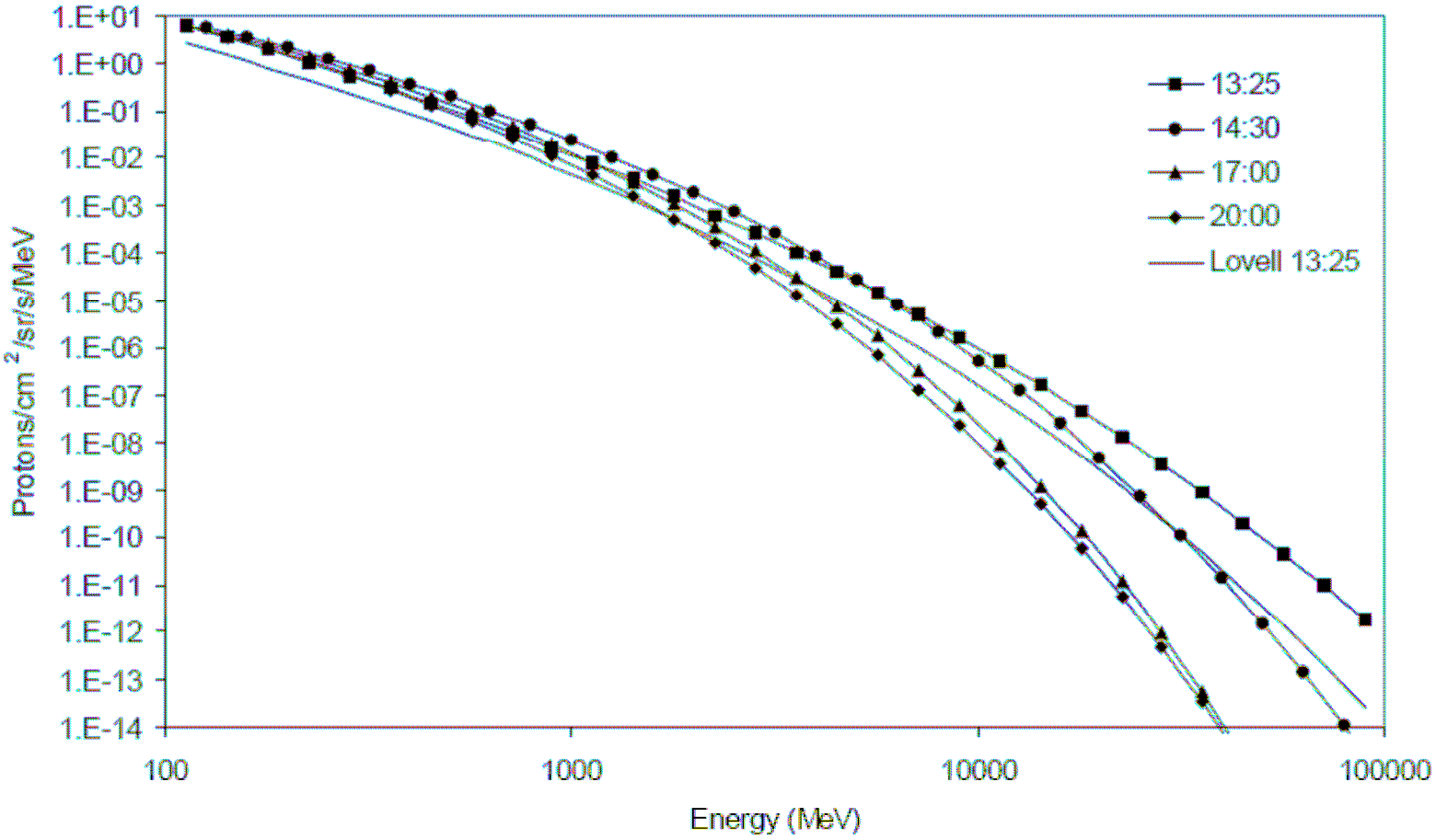
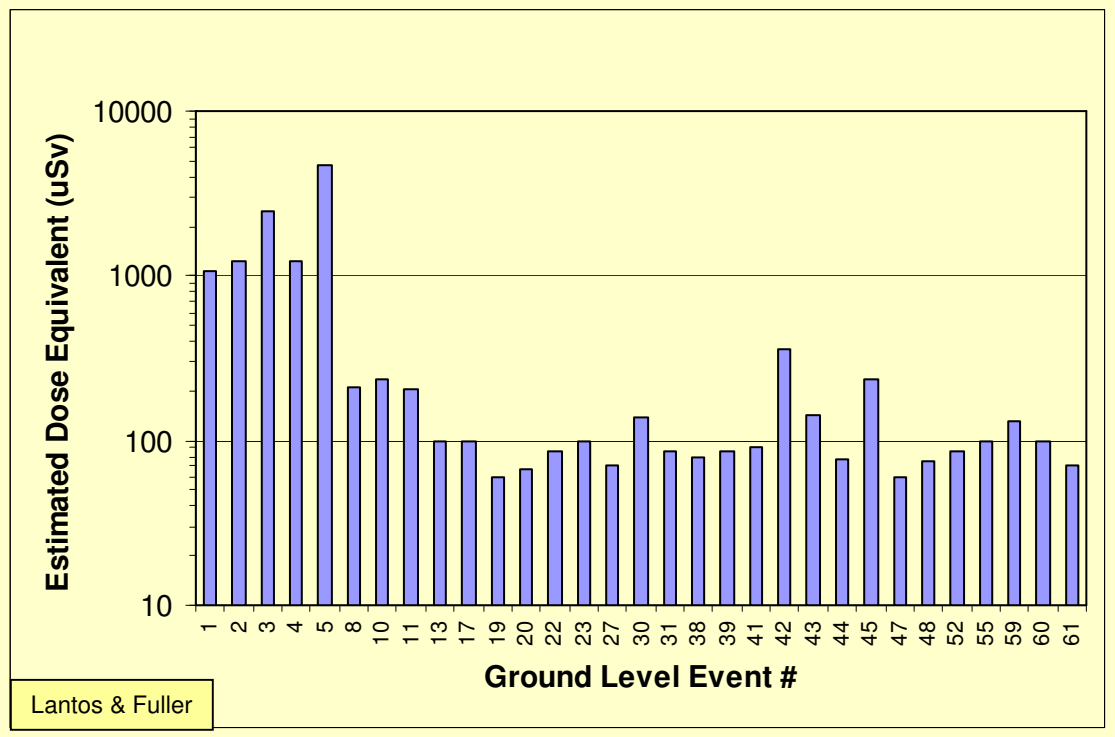


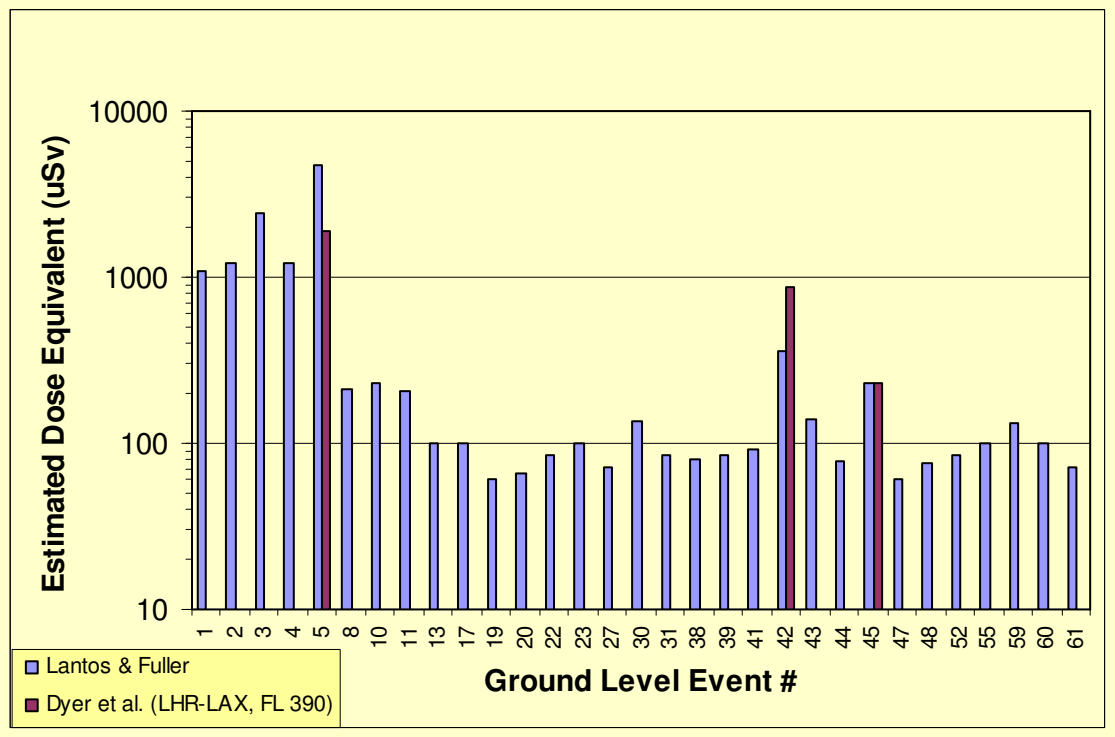
Fig.1. Solar proton spectra derived at several times during the 29 September 1989 event show softening with time. Comparison is made with a spectrum derived by Lovell et al. (1998).

Exposure Calculations for Solar Particle Events

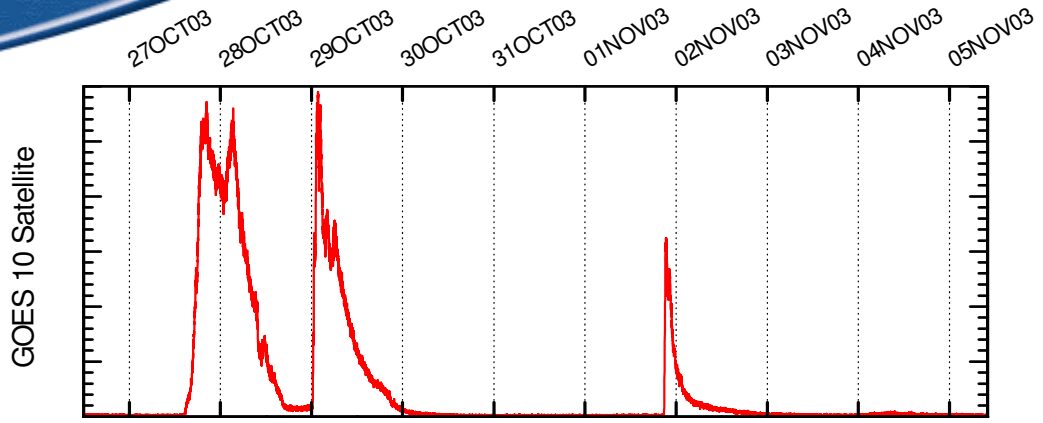


Worst-case exposure for typical CDG – LAX flight

Exposure Calculations for Solar Particle Events



Previous Attempts to Measure SPE doses



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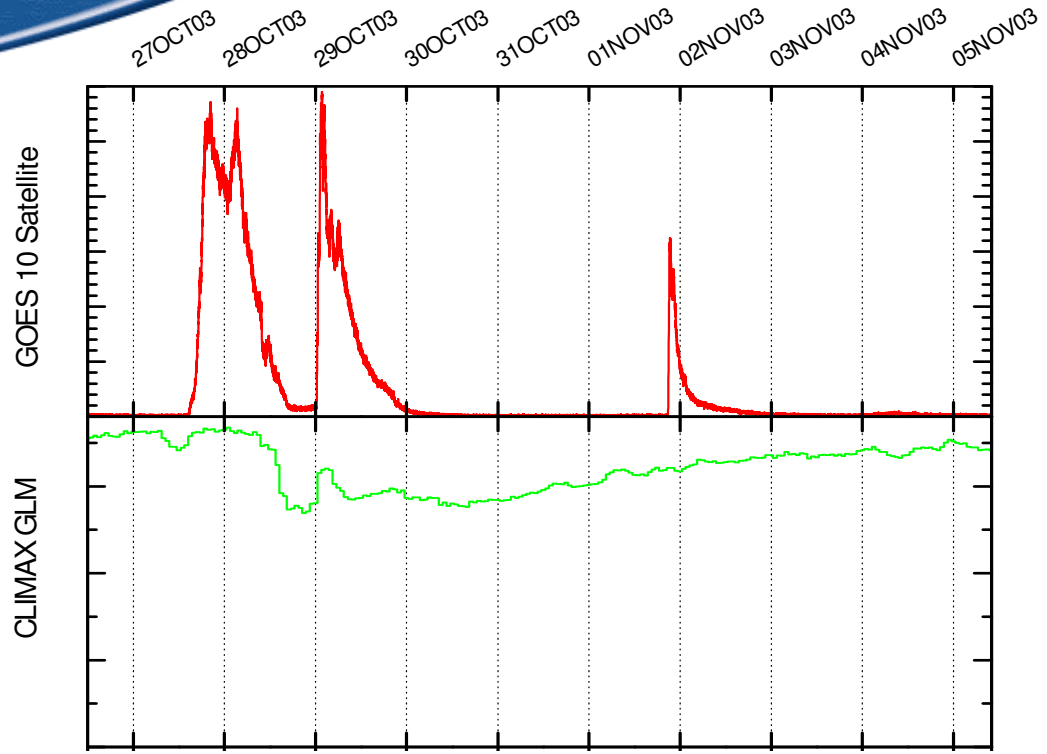
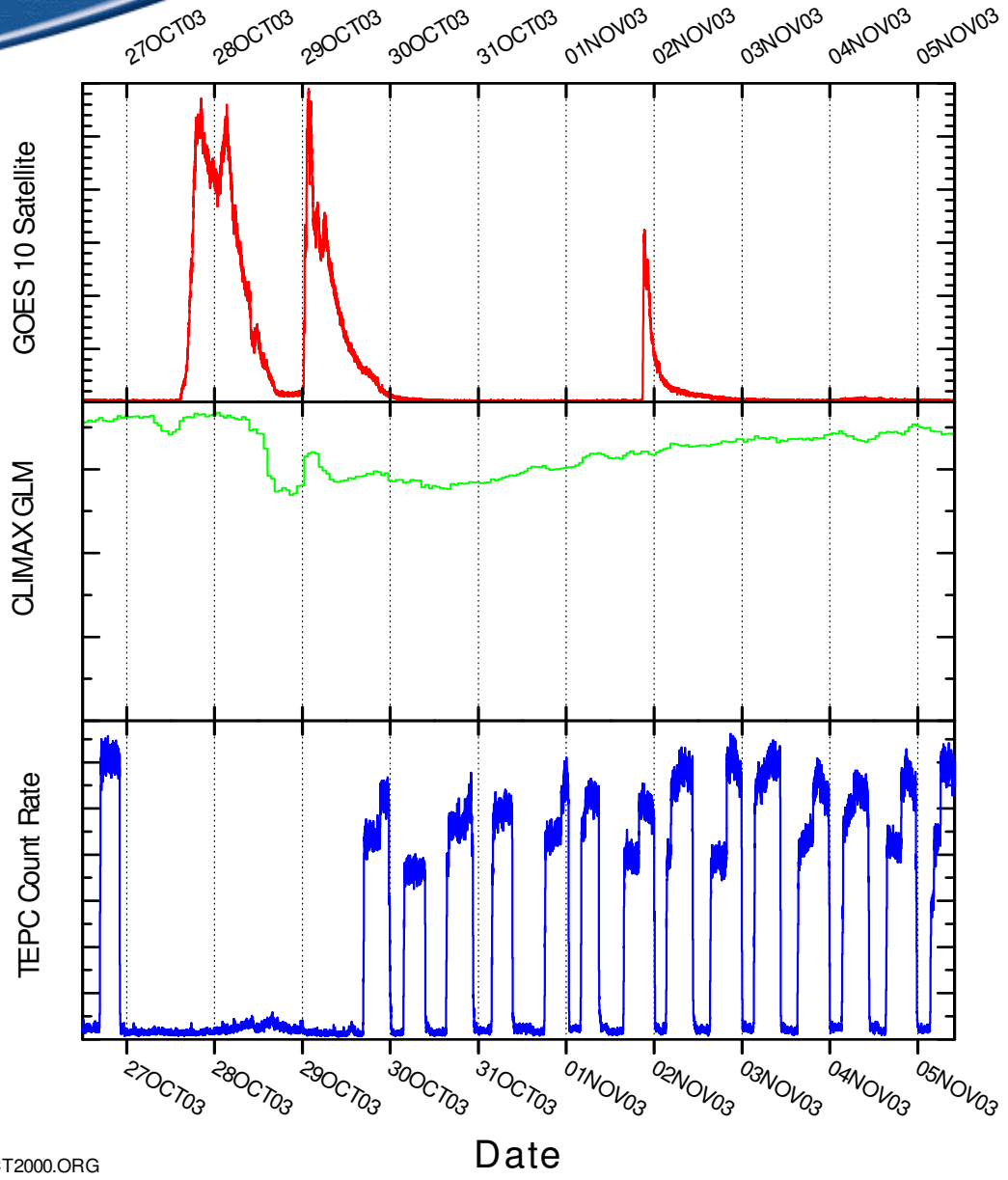


Previous Attempts to Measure SPE doses

Moral:
Never put all your eggs in one basket!



‘FlareWatch’

Aim: To fly small, robust instruments
(THERMO EPD-N2s) on multiple aircraft

Partners: BA (probably!)

Launch: Spring 2007 (?)

Summary

SPEs - Usually caused by Coronal Mass Ejections (often associated with Solar Flares).

CMEs - Massive bursts of particles catapulted into space by 'magnetic whiplash'
Not a problem unless CME trajectory results in a collision with the Earth
Not usually as energetic (i.e. penetrating) as GCR, but much higher fluences (**x10^5** more)

GLEs - Instantaneous dose rates can increase **100-fold** or more at aircraft altitudes
Associated magnetic storms can alter local earth potentials (Canadian blackouts, **1859 event!**)

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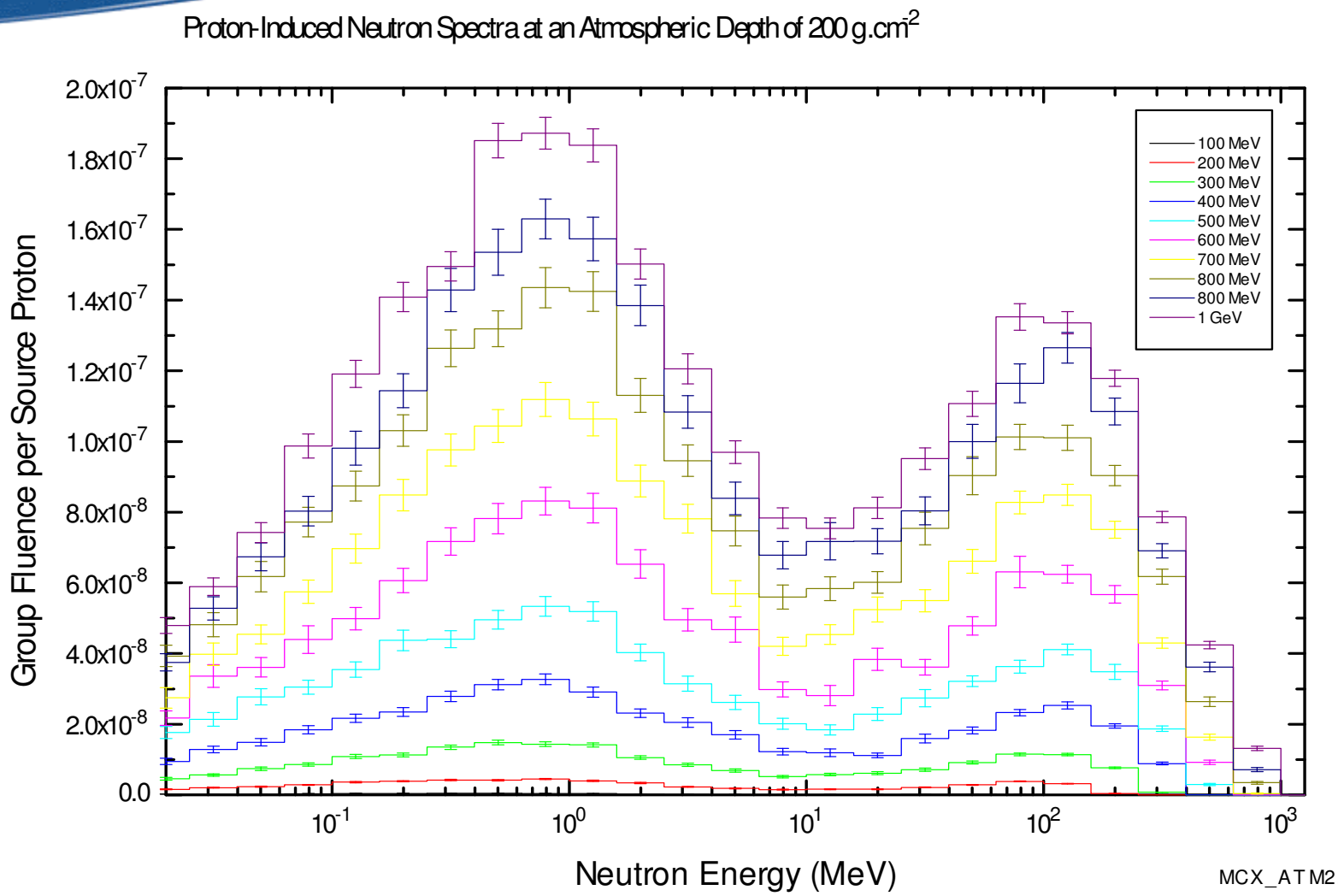
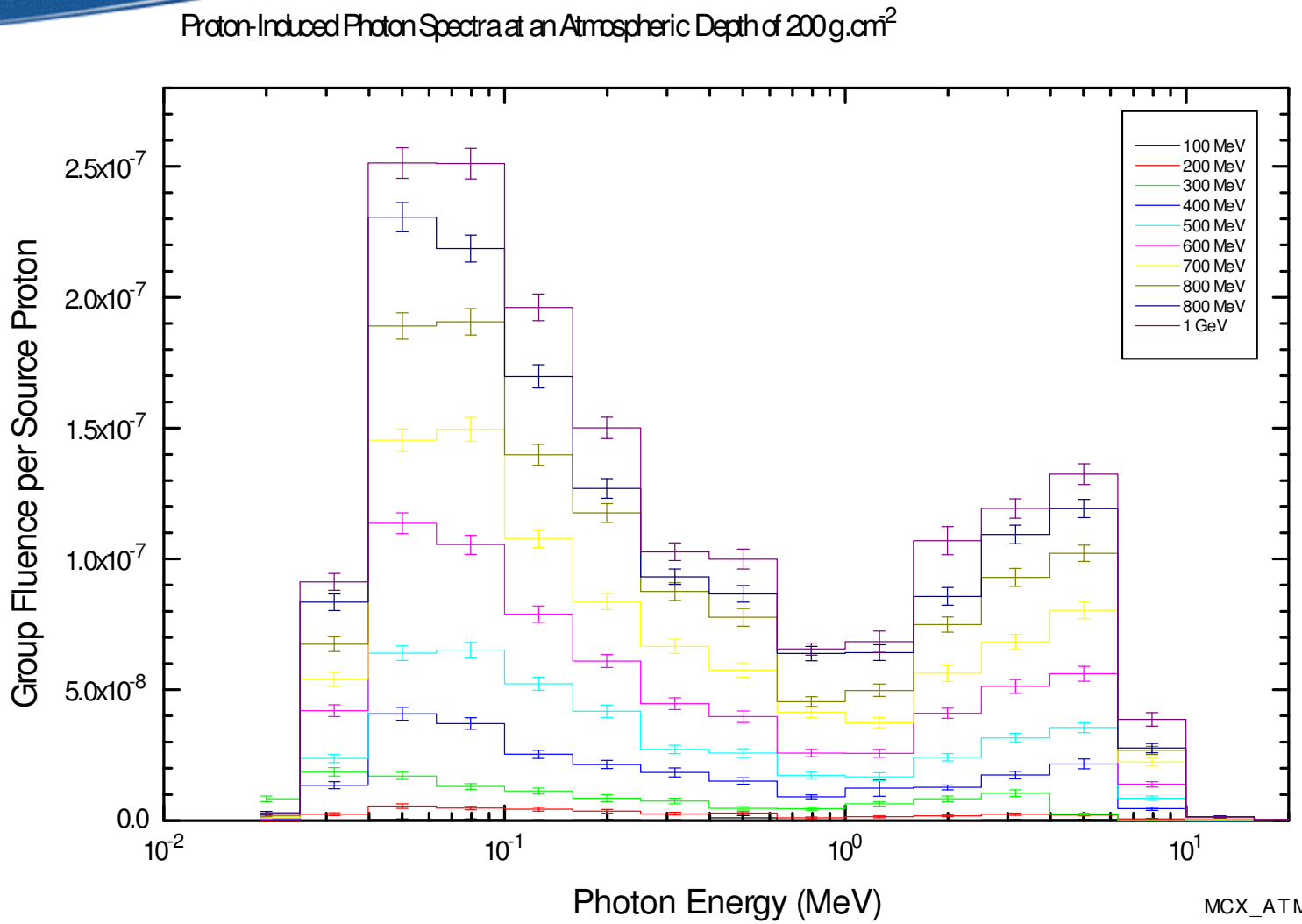
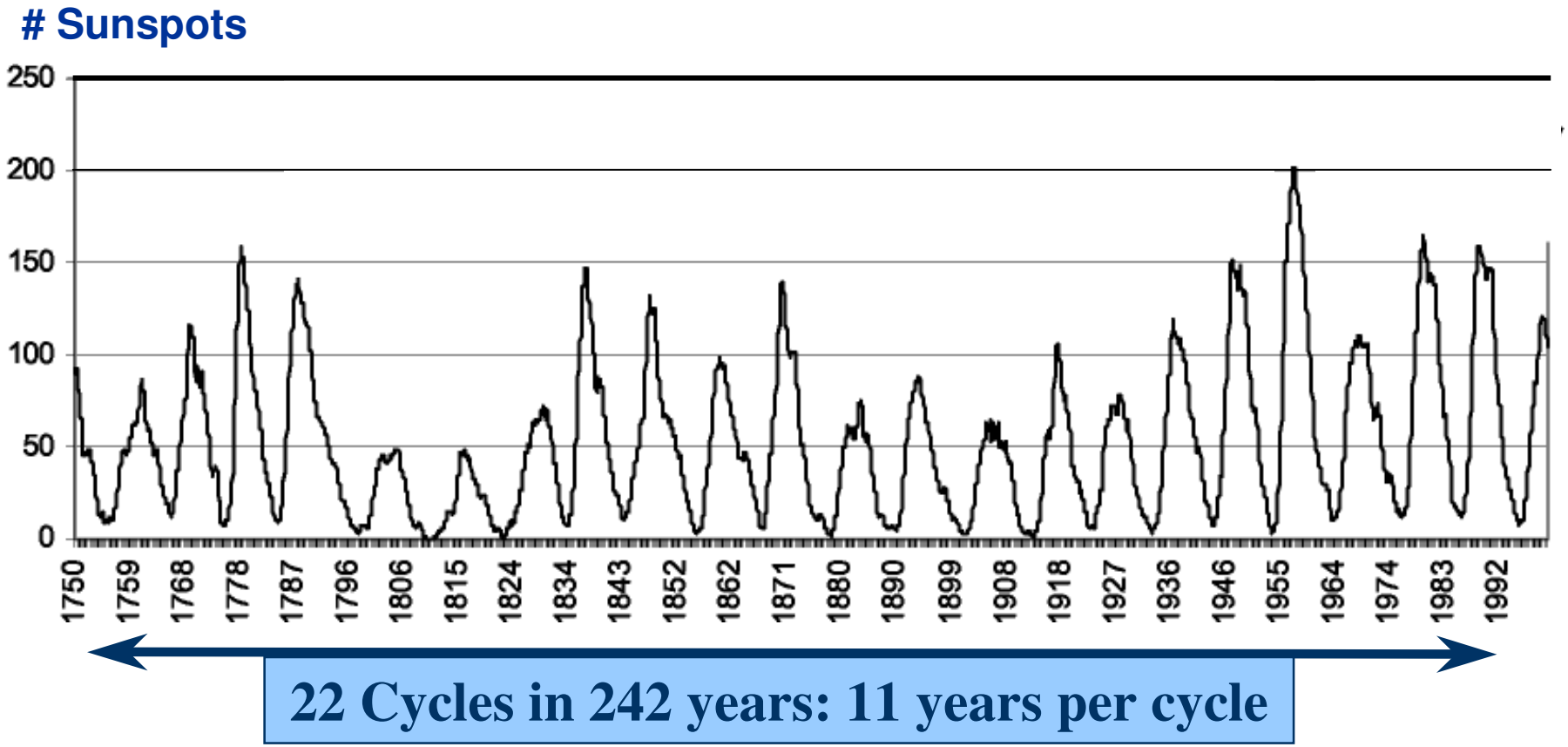
Variation in Neutron Spectrum with Proton Energy



Variation in Photon Spectrum with Proton Energy



The Solar Cycle



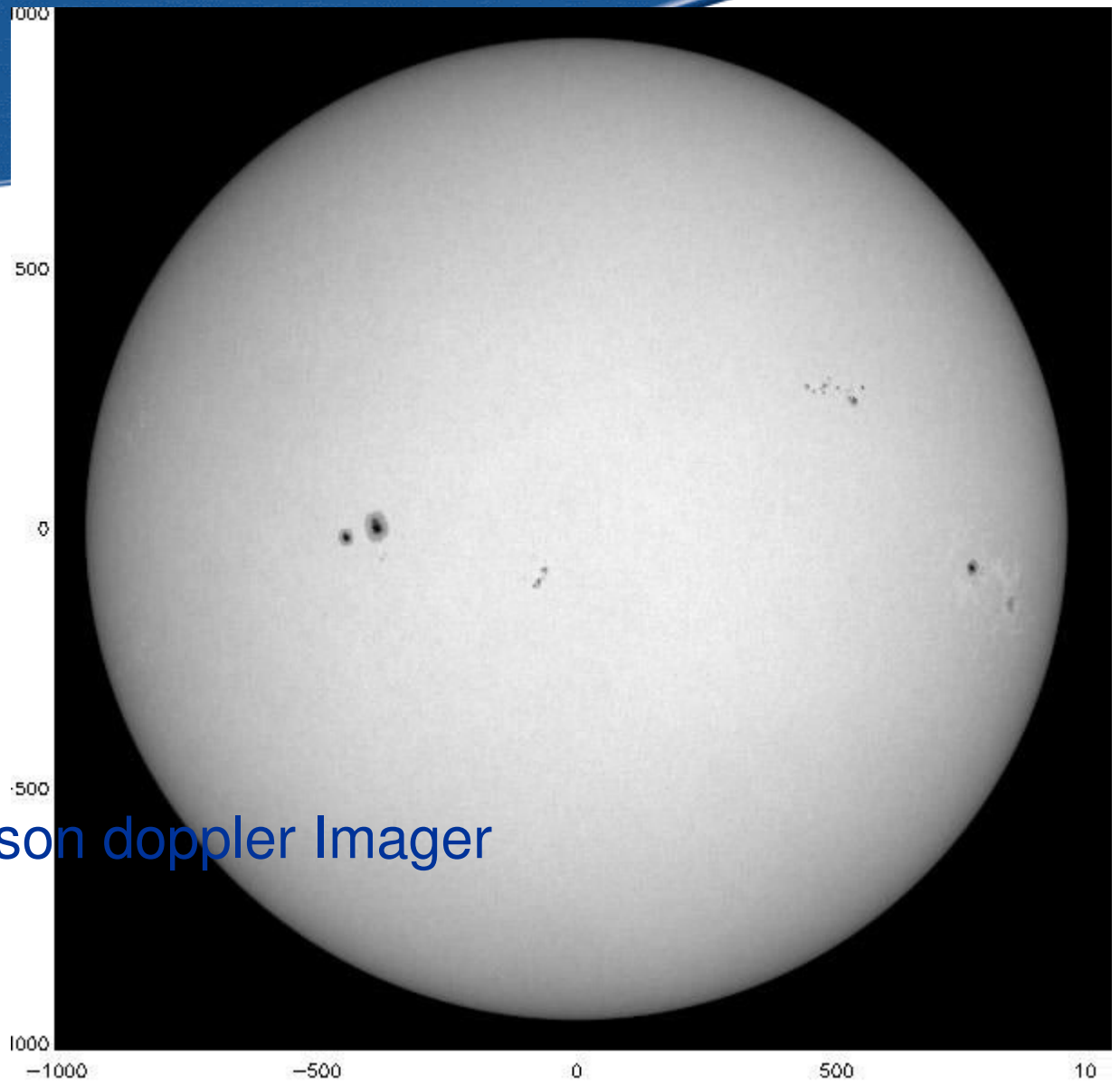
Summary

Air crew have **higher** occupational radiation exposures than typical nuclear workers

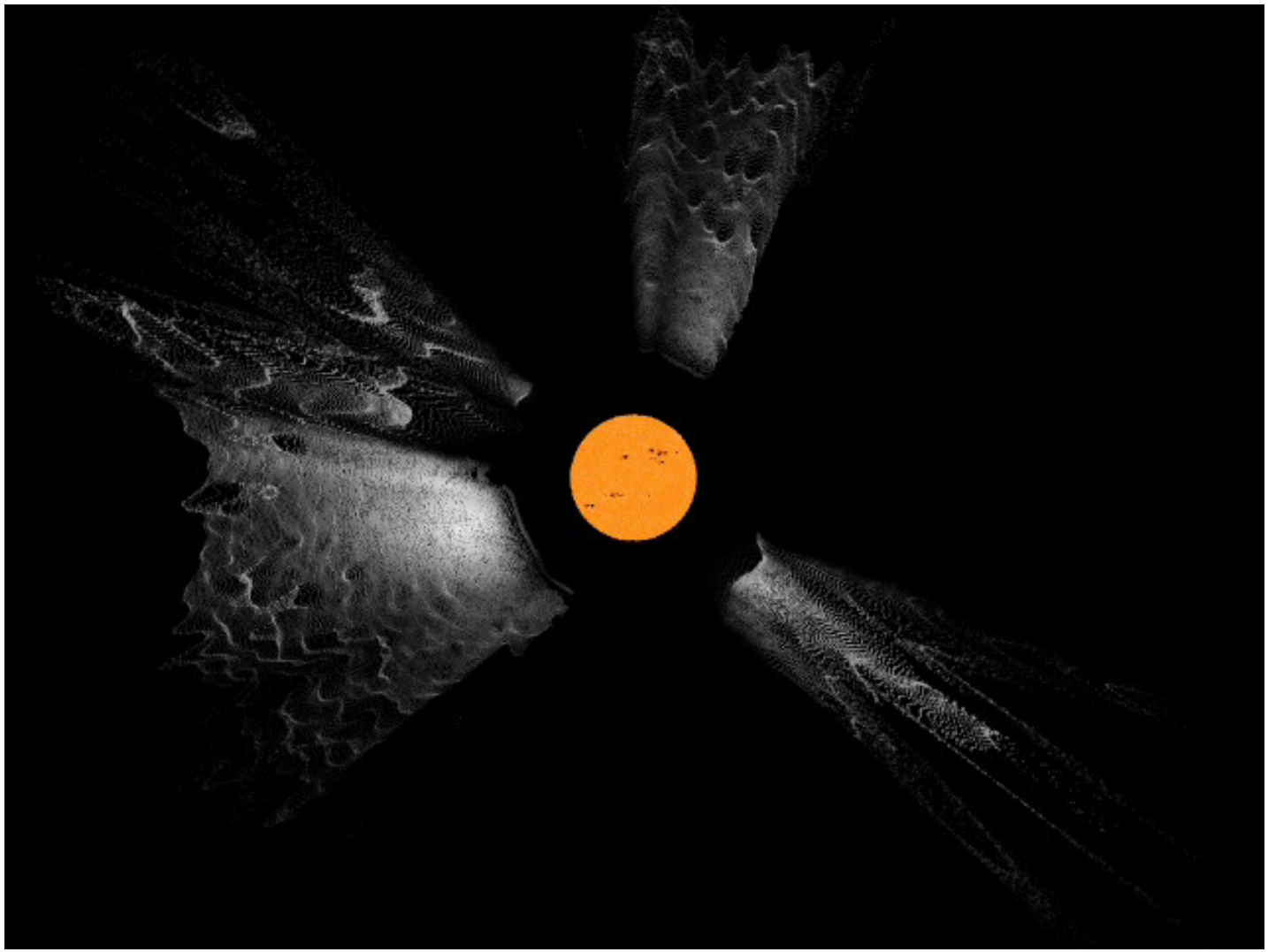
The exact exposure depends on **altitude, latitude** and **duration** of a given flight, as well as the **solar activity**

NPL has collaborated in a massive in-flight measurement programme to demonstrate that **software** used to calculate crew doses **performs reasonably well** (long-term)

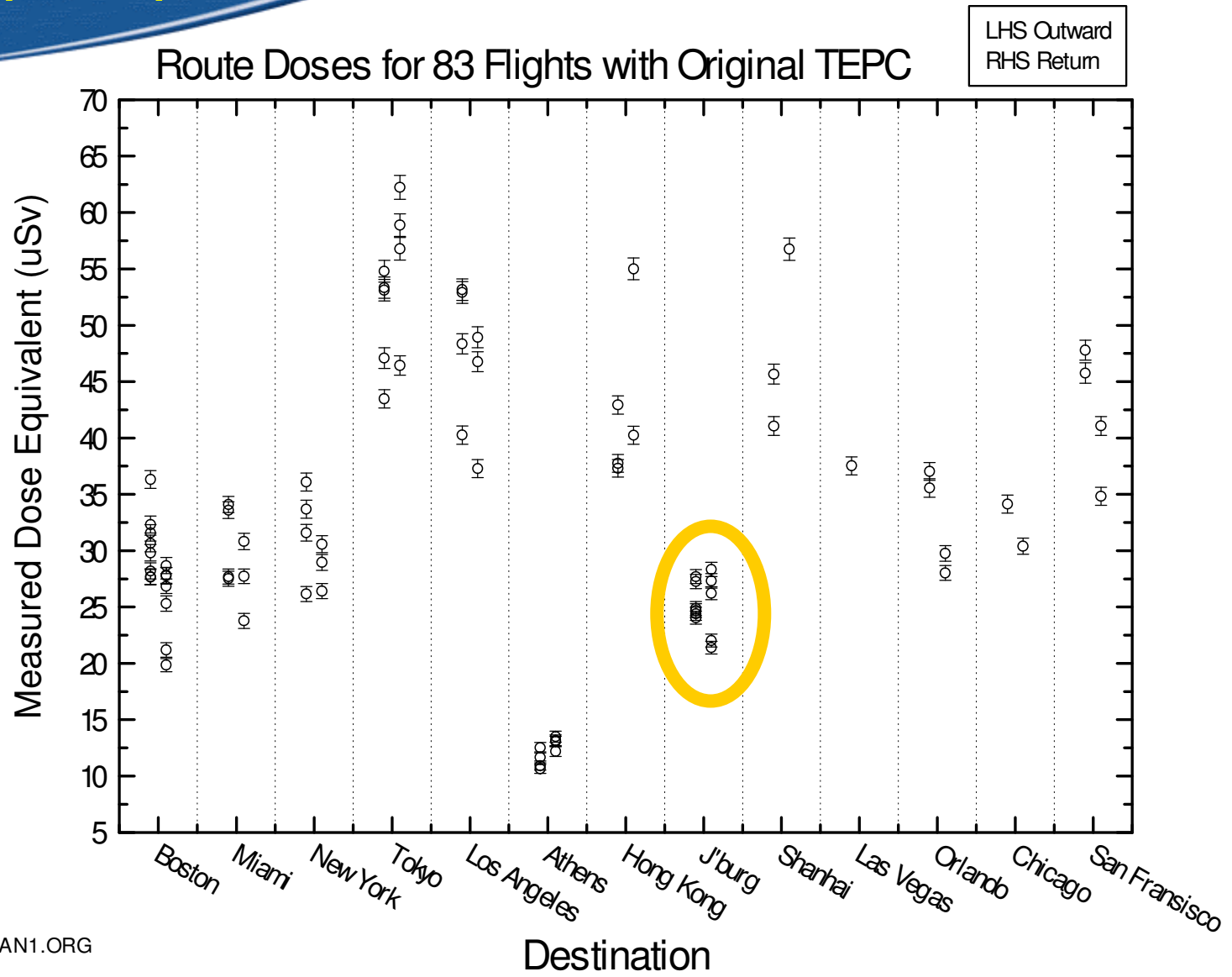
Further Work under way in the area, via collaborations with
MSSL and SELEX (TEPC development)
BA ("Flarewatch" solar particle event monitoring)



Michelson doppler Imager



Typical Route Doses for Solar Max (2000)



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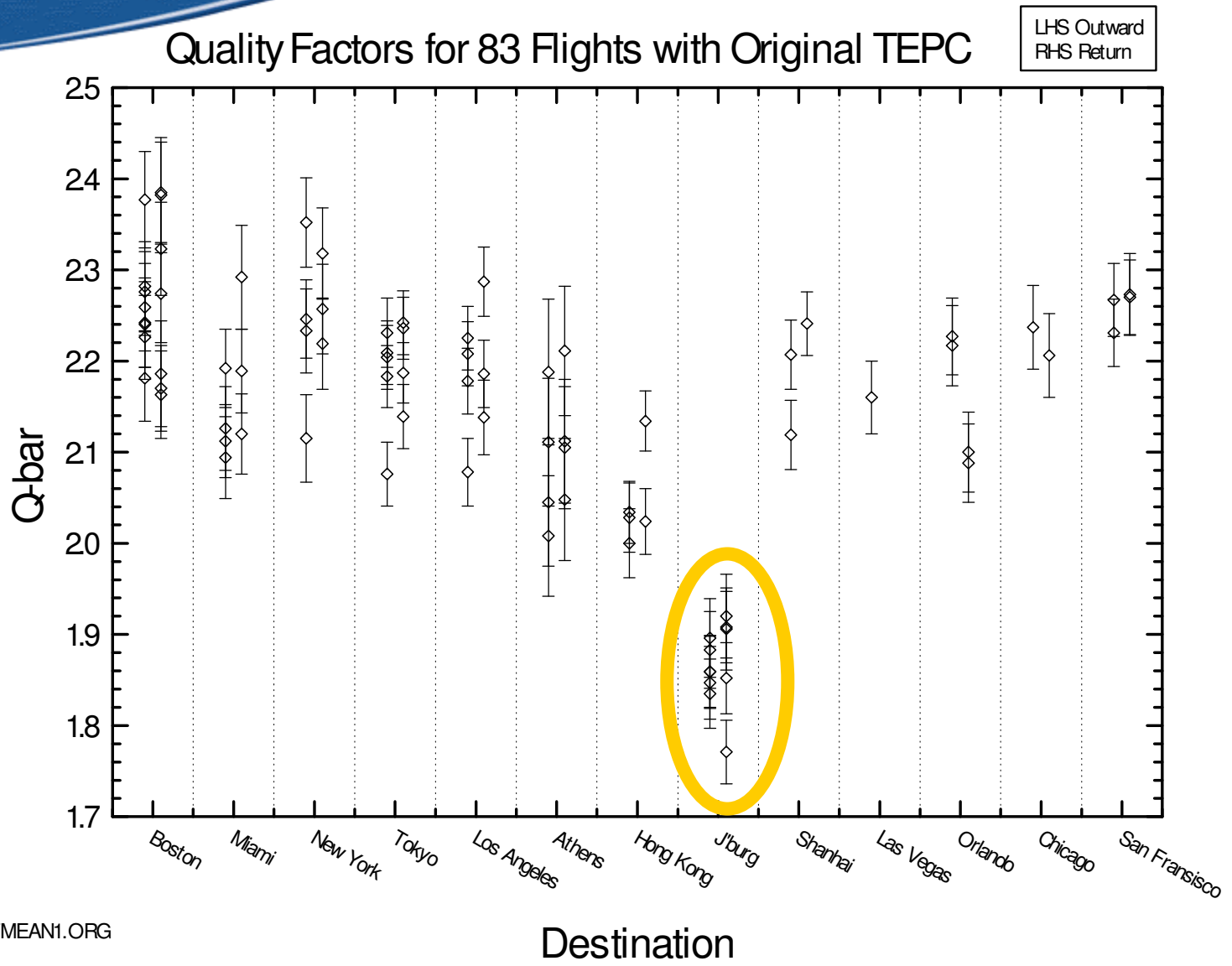
Mean Quality Factors



FLTMEAN1.ORG

Measuring Cosmic Ray Doses at Aircraft Altitudes

Questions ?

Credits

Animations: ESA / NASA

Images:

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