

# **The SANAP Cosmic-Ray Neutron Monitor Programme**

**Harm Moraal**

**North-West University  
Potchefstroom**

# Our group

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1. Harm Moraal - PI
2. Helena Krüger - Co-I
3. Gert Benadé – electronics engineer
4. Anne Mans – data and station manager
5. Godfrey Mosotho – M.Sc. student
6. Renier Fuchs – M.Eng. student
7. Ruan Nel – M.Eng. student
8. Henrdik Krüger – expedition member SANAE

Pieter Stoker – Emeritus and founder

# Cosmic Rays

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- Charged **particles** - 90% protons, 5% He nuclei, 3% heavier atomic nuclei, 2% electrons
- Characterised by very high energies ( $10^6$  -  $10^{20}$  eV)

**One particle = cricket ball at 140 km per hour.**

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# Come from the Cosmos .....

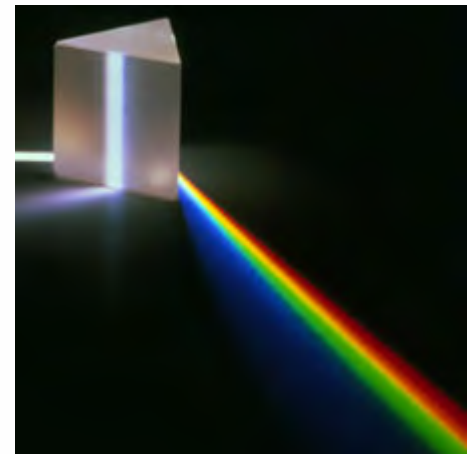


# Particle vs. Photon Astronomy

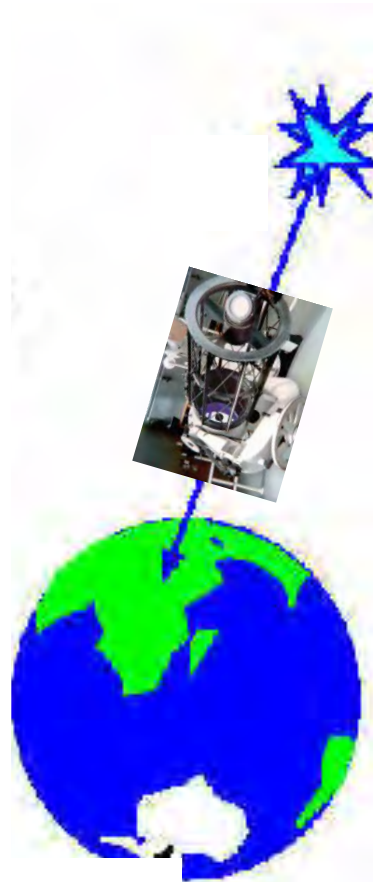


## Photons

1. Where
2. How bright
3. Colour

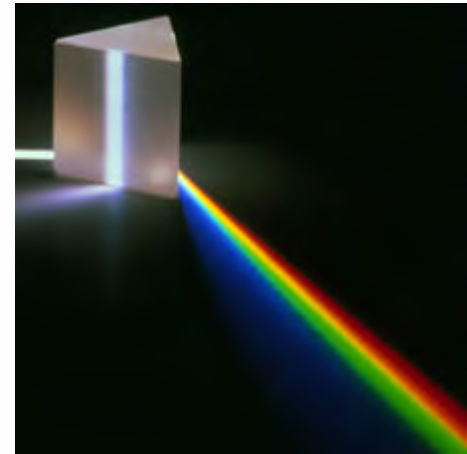


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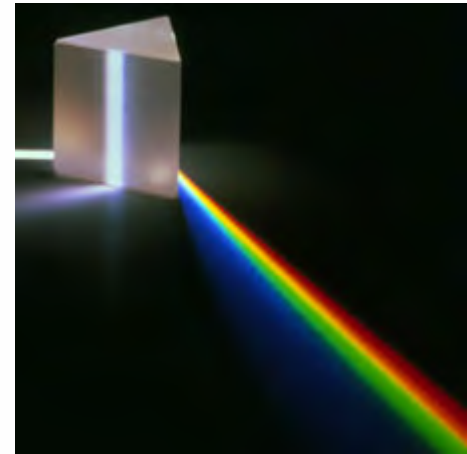
**Particles:**  
**No such information**  
**Because of magnetic fields**

**.....like a bead on an**  
**elastic band**



## Photons

1. Where
2. How bright
3. Colour



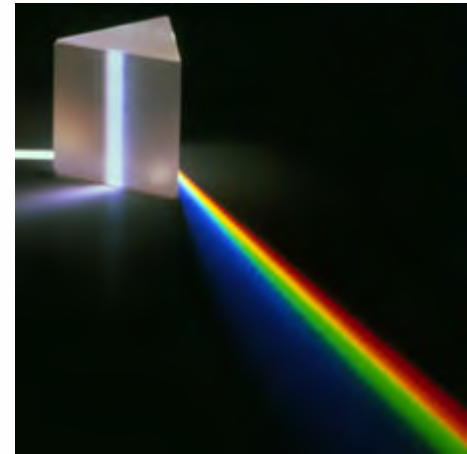


# Particle vs. Photon Astronomy



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# Particle vs. Photon Astronomy

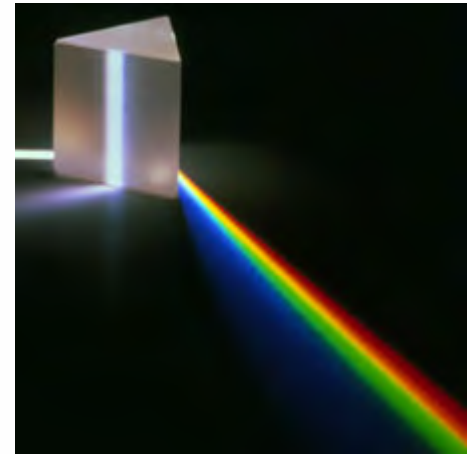
**Particles:**  
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## Photons

1. Where
2. How bright
3. Colour



# Victor Hess, 7 August 1912



# Victor Hess, 7 August 1912



**100 years later (+2)**



**Cosmic Rays in the Heliosphere**

**Harm Moraal**

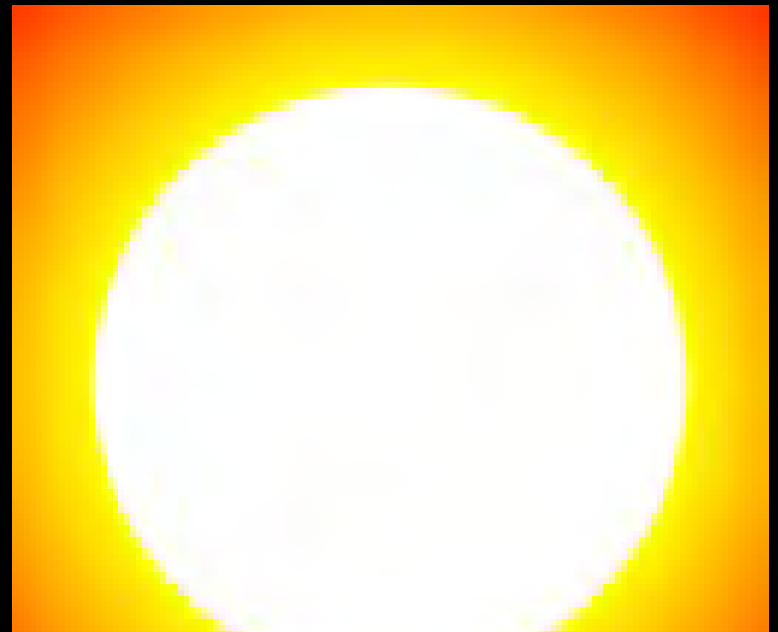
**North-West University**

**Potchefstroom, South Africa**

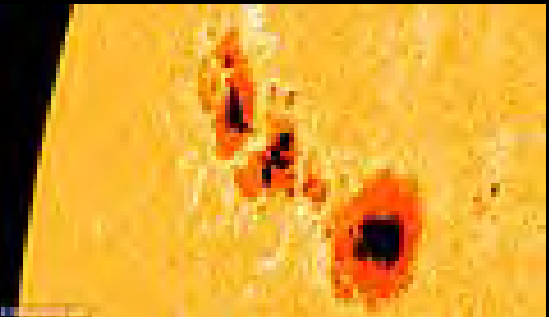
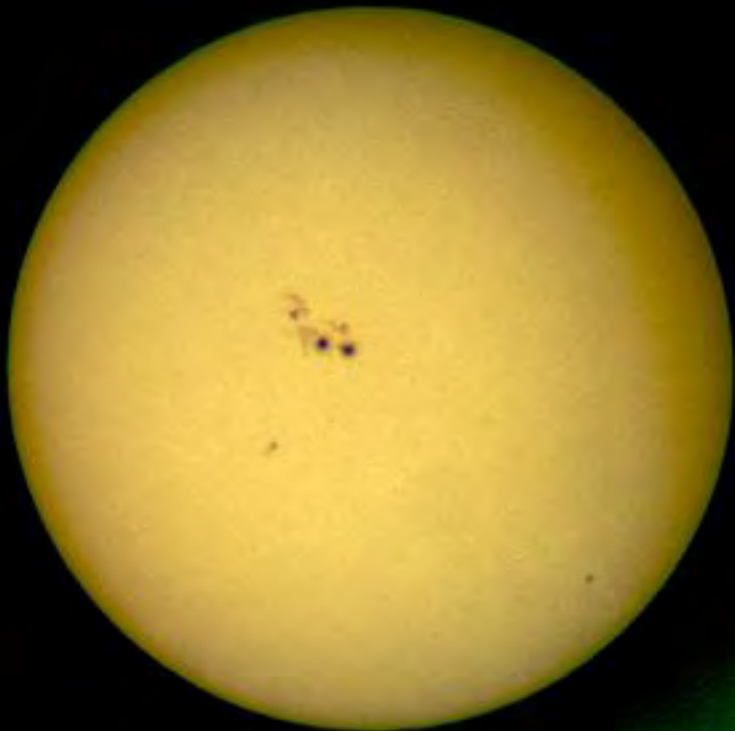
# Bad Saarow Railway Station



# The Sun

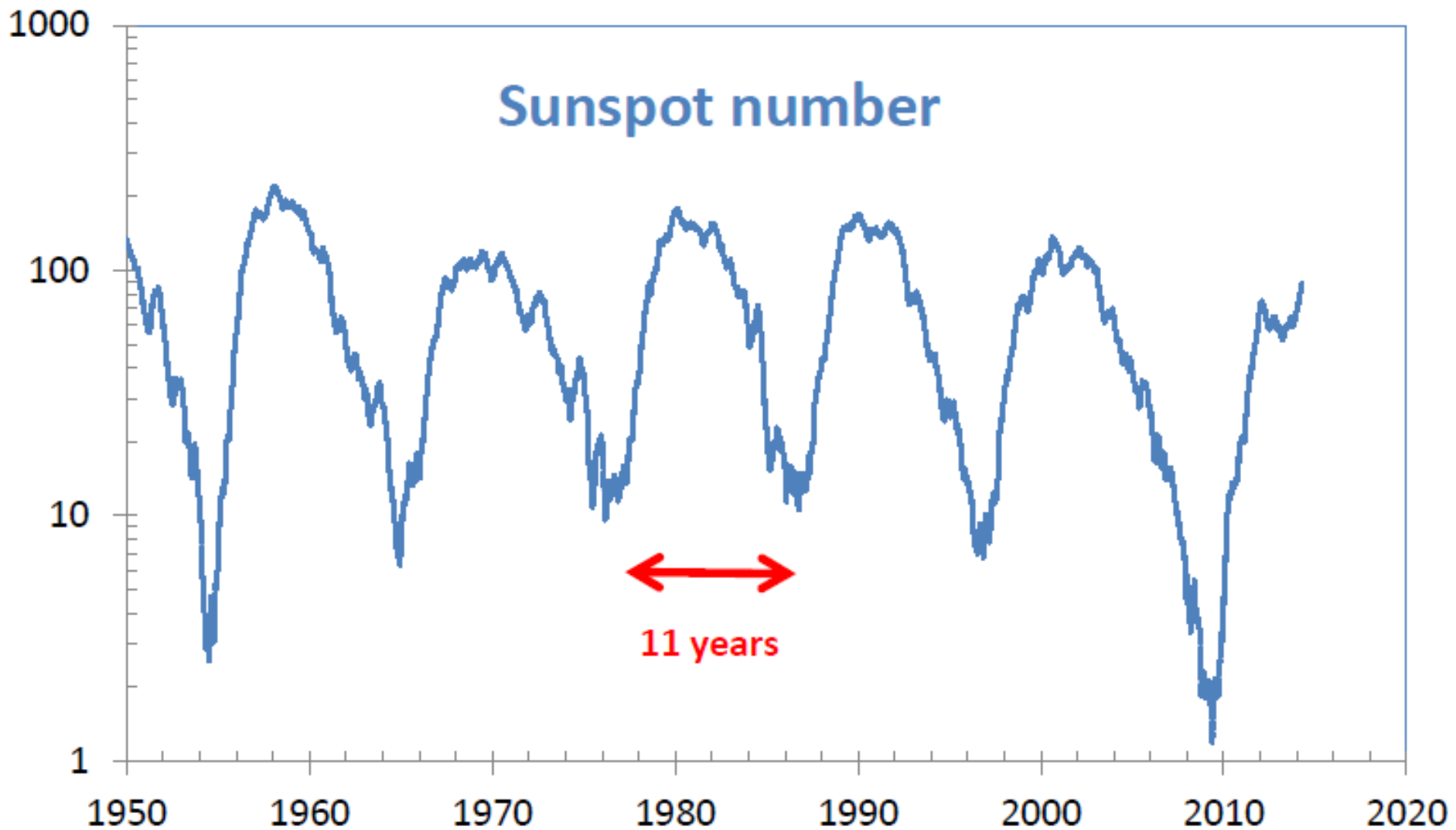


# Sunspots

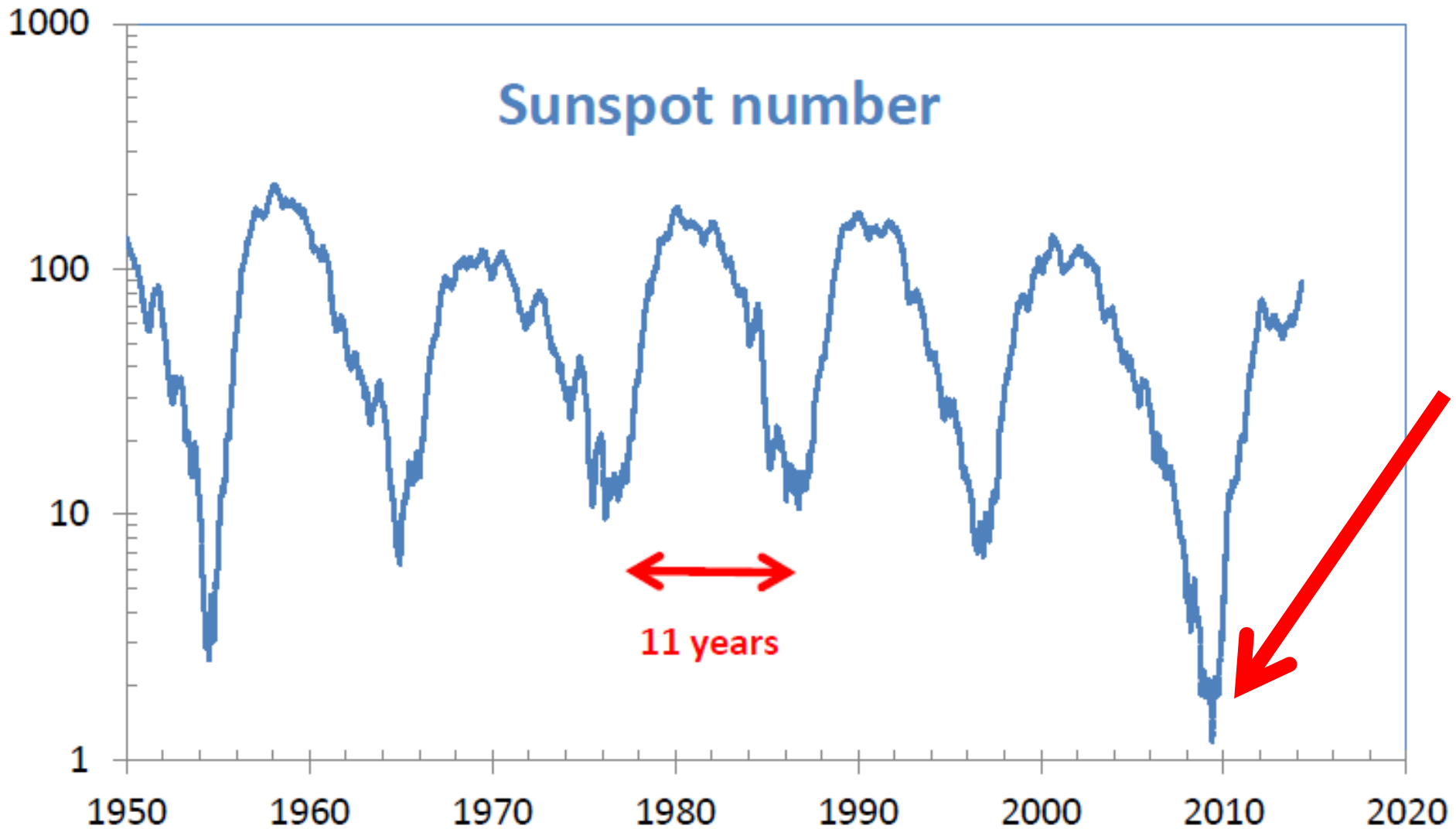




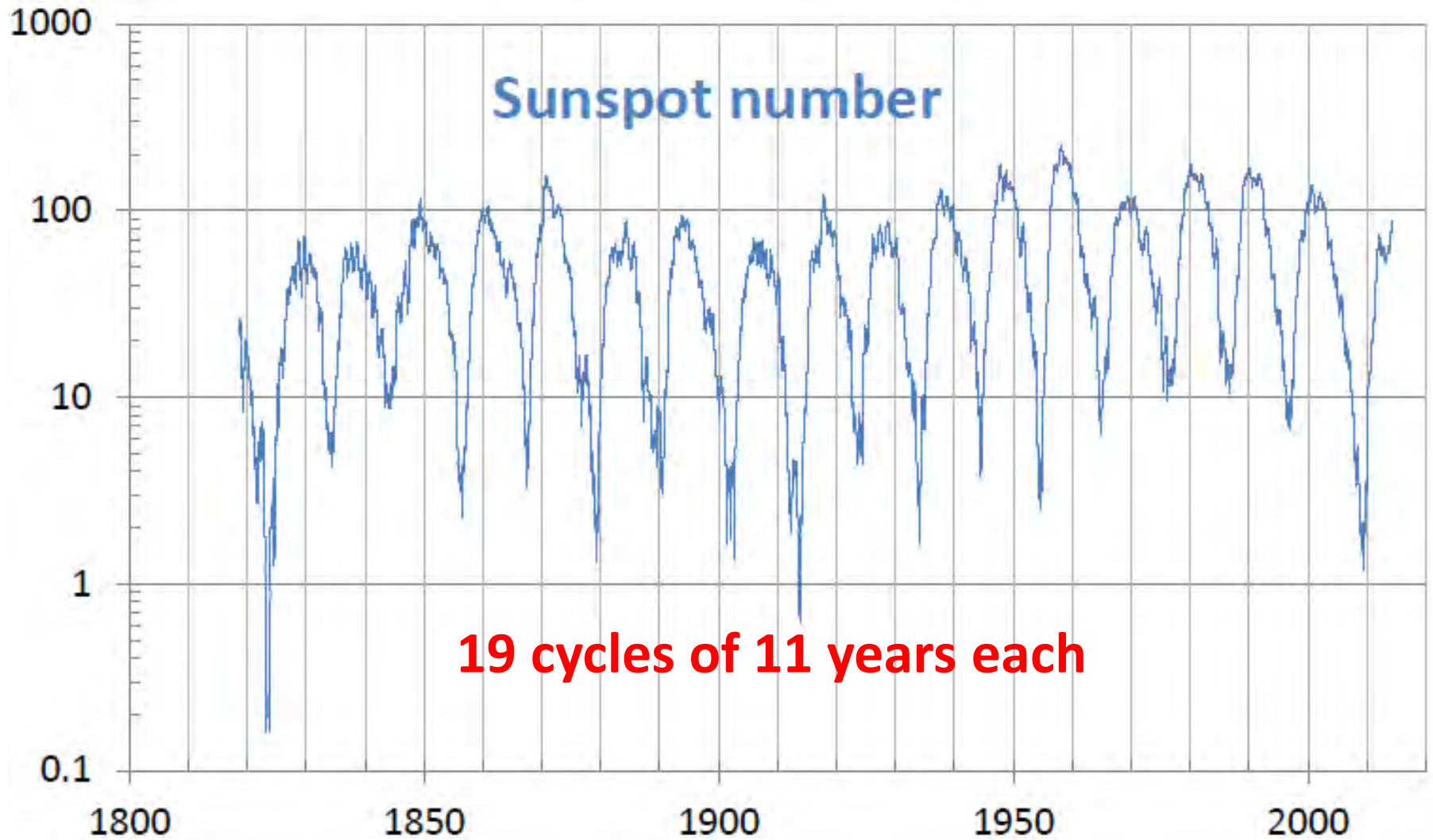
# Sunspots



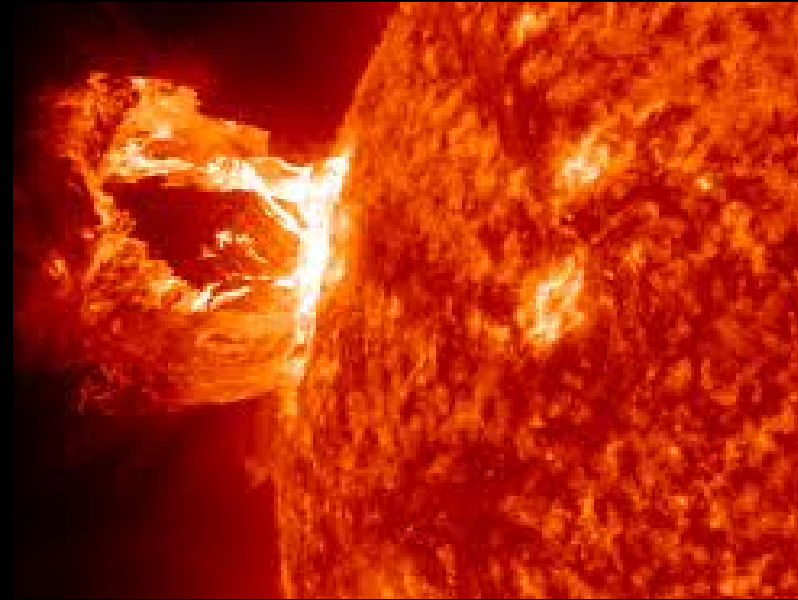
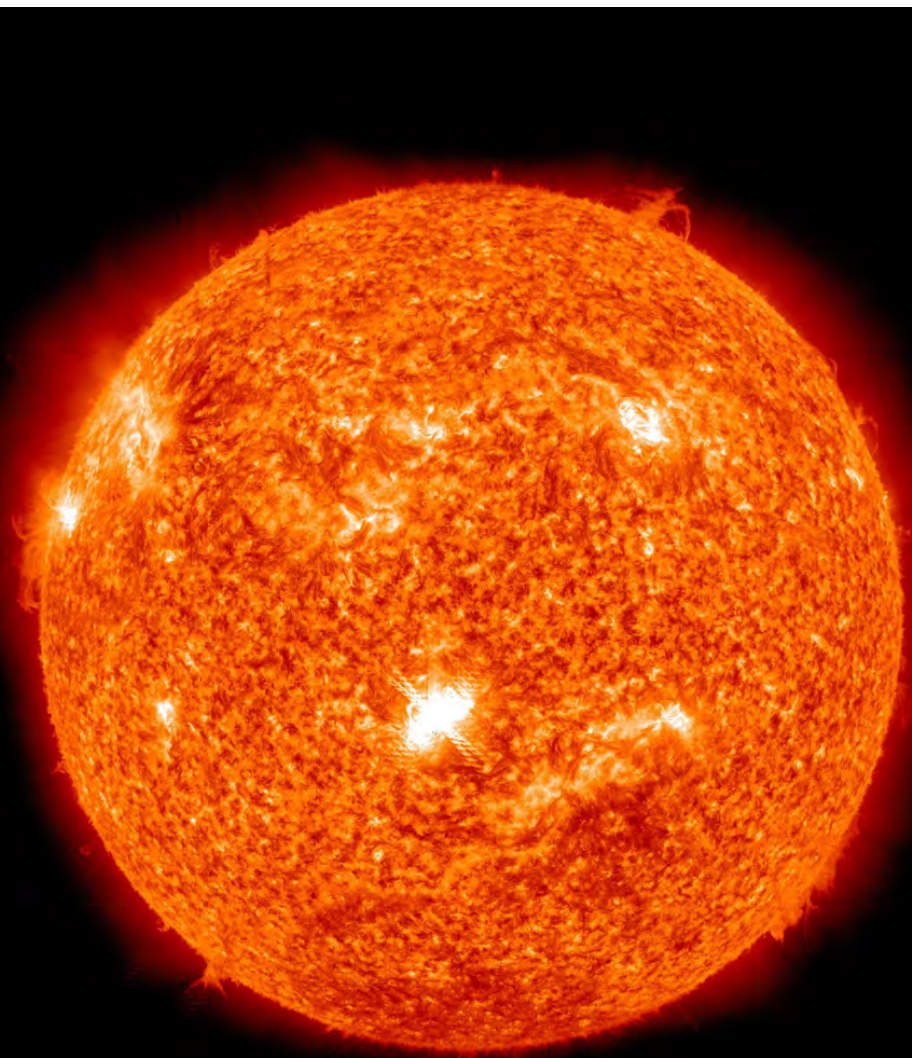
# Sunspots



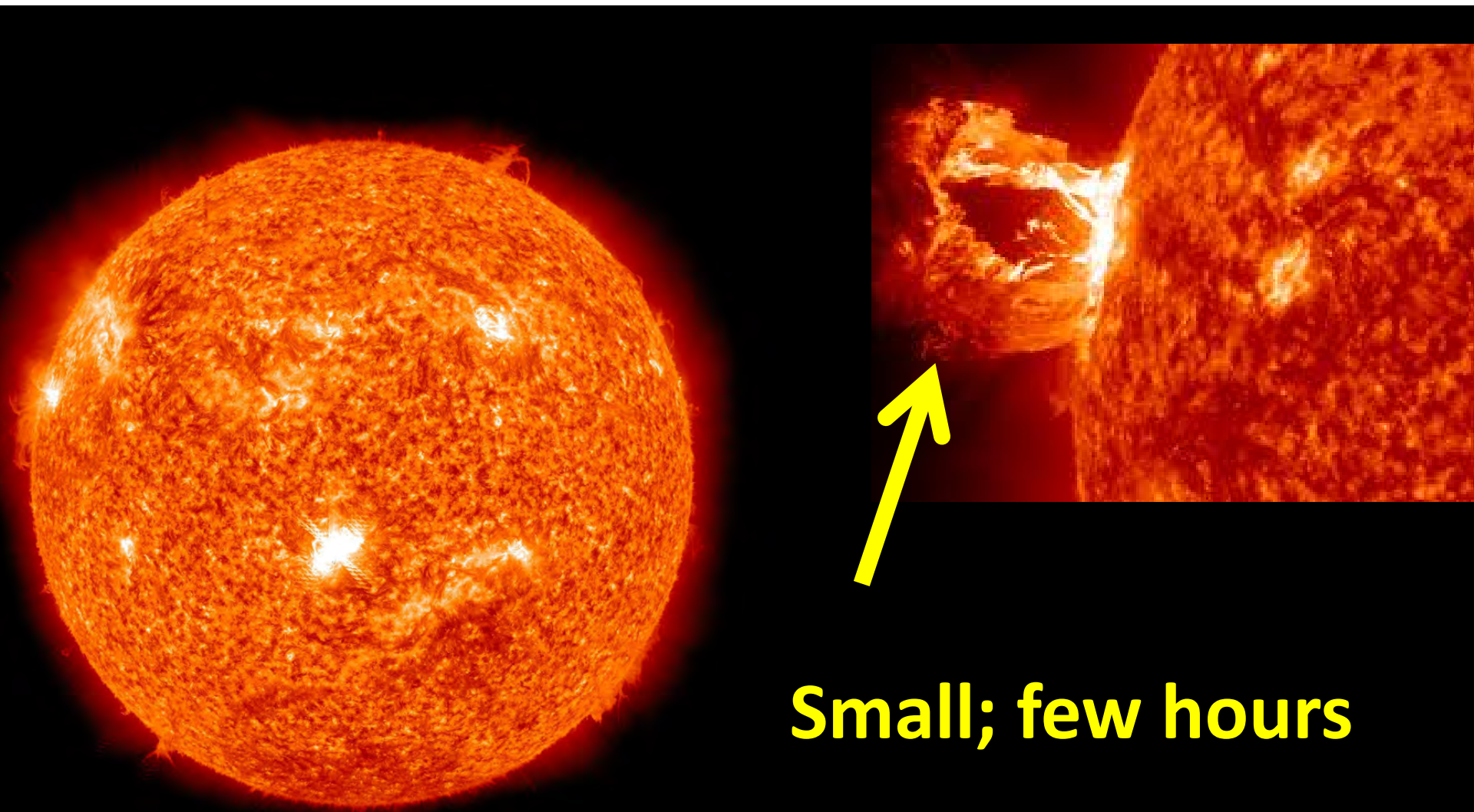
# Sunspots since 1818



# Solar Flare

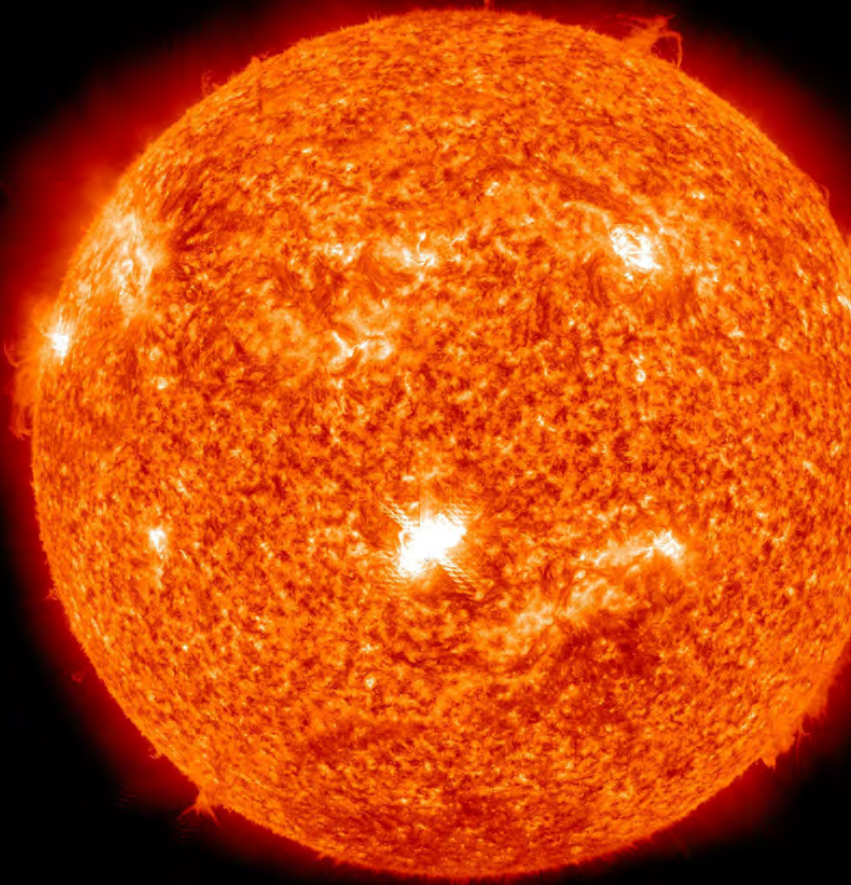


# Solar Flare

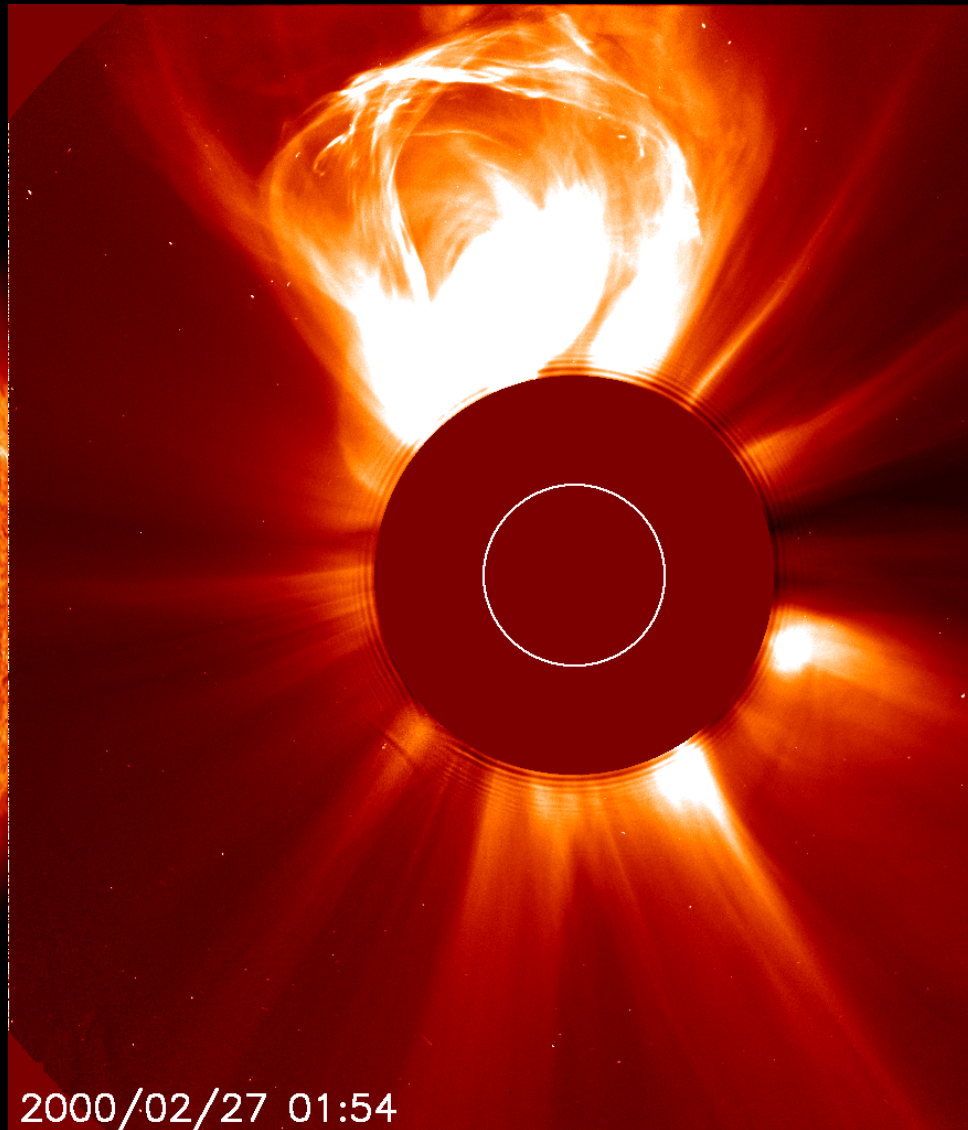


**Small; few hours**

# Coronal Mass Ejection



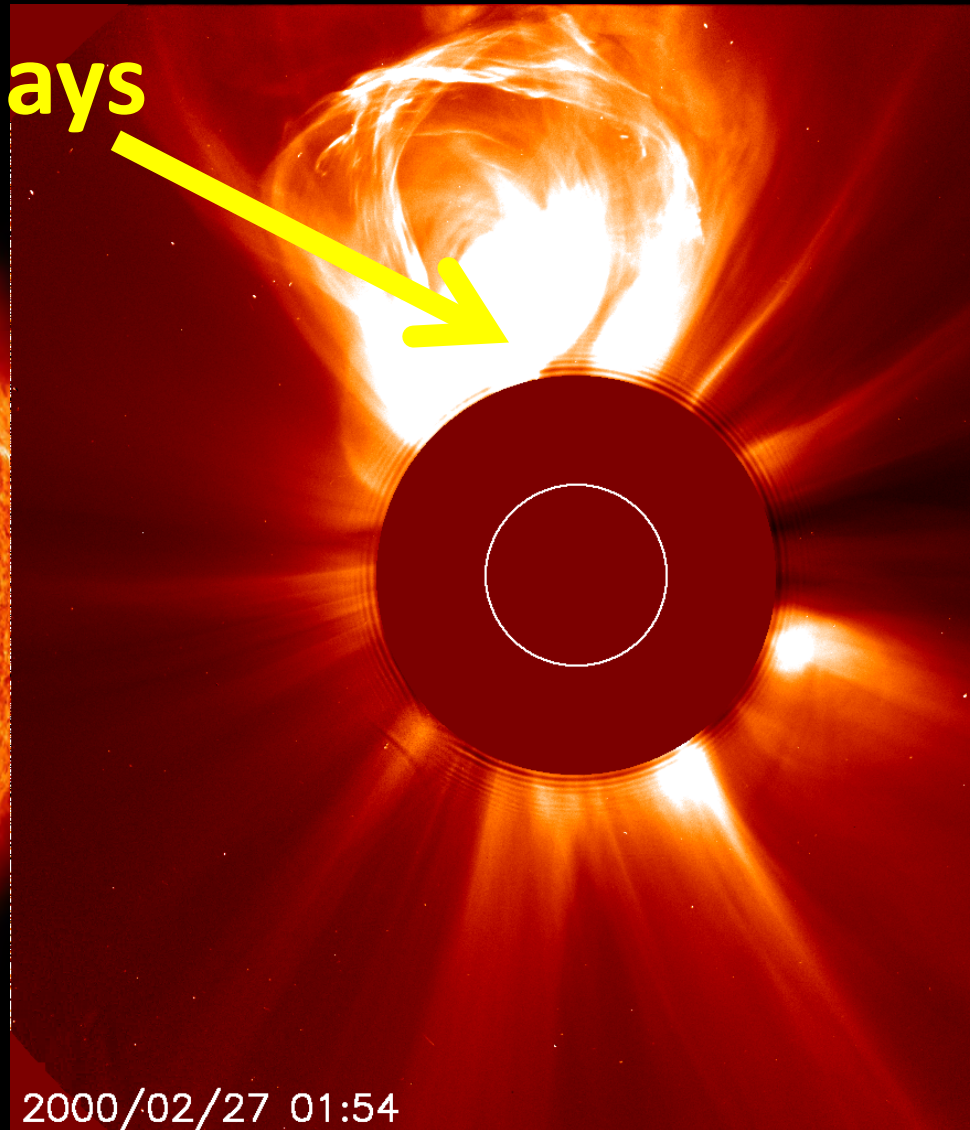
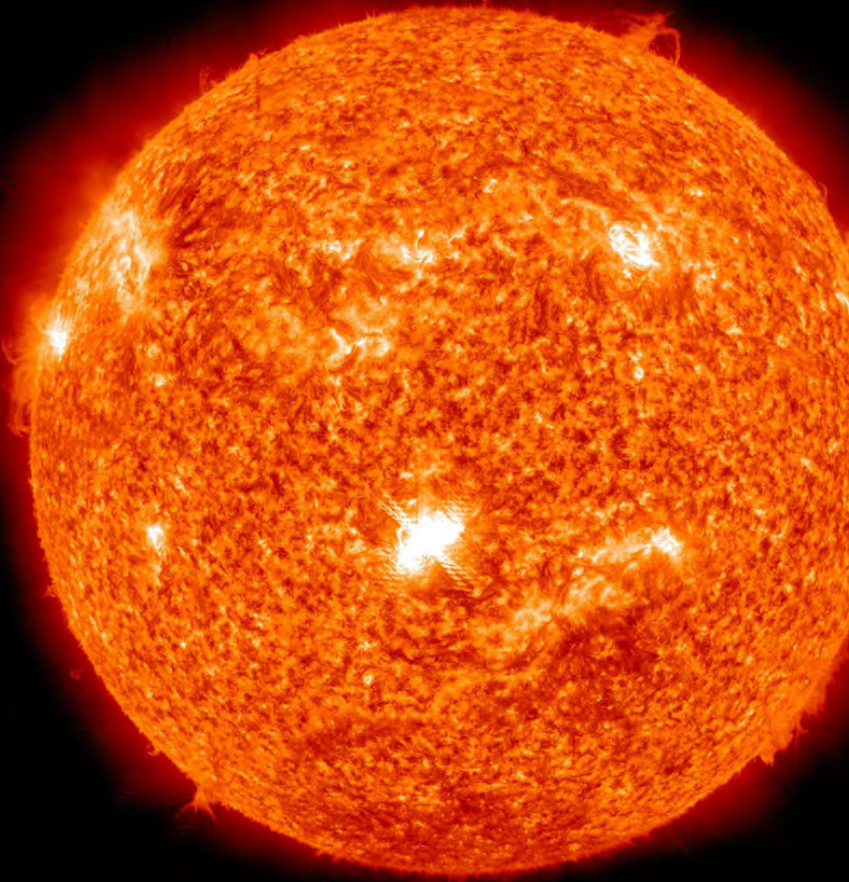
SDO/AIA 304 2011-02-13 17:36:45 UT



2000/02/27 01:54

# Coronal Mass Ejection

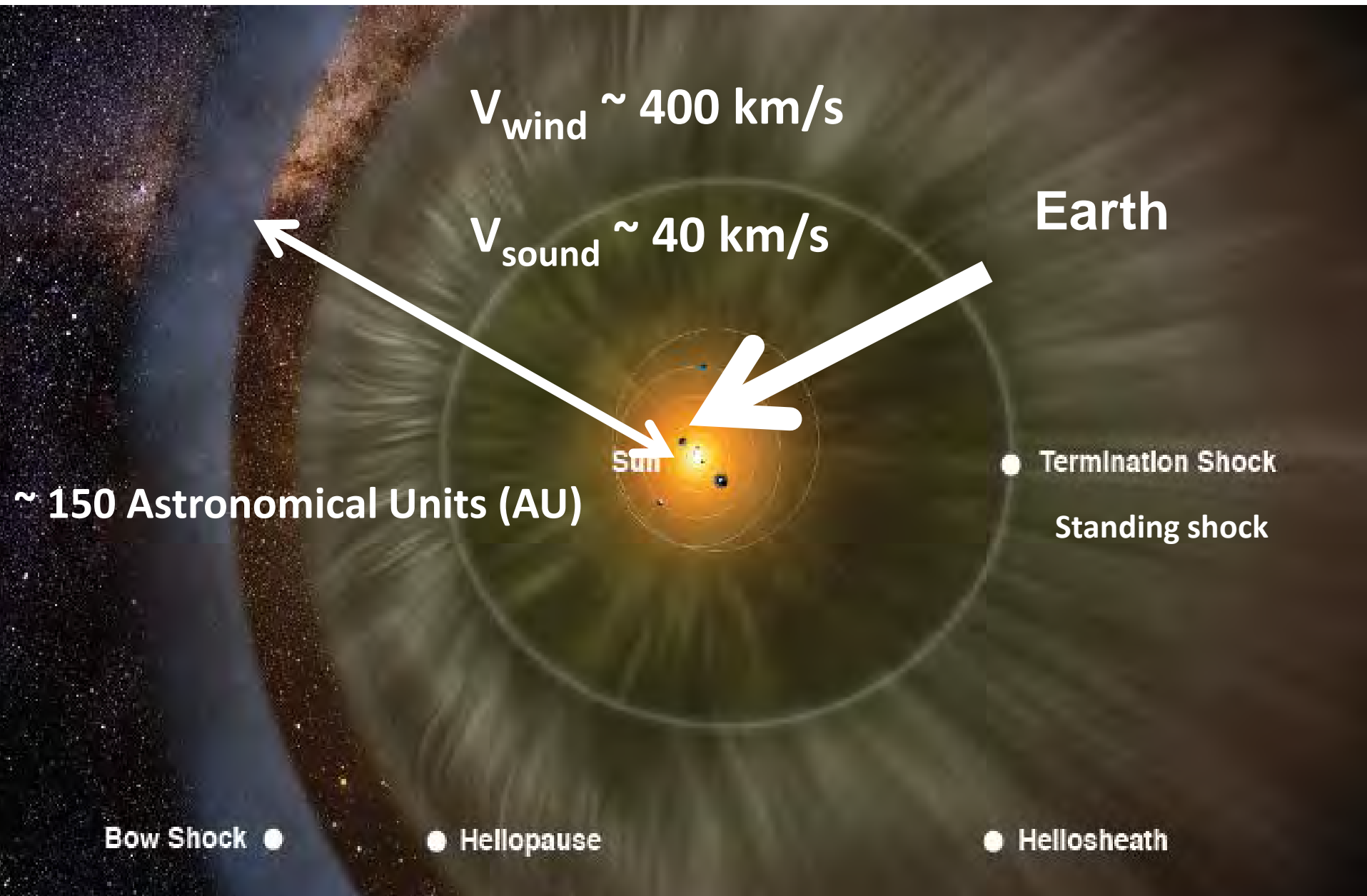
**Big; days**



SDO/AIA 304 2011-02-13 17:36:45 UT

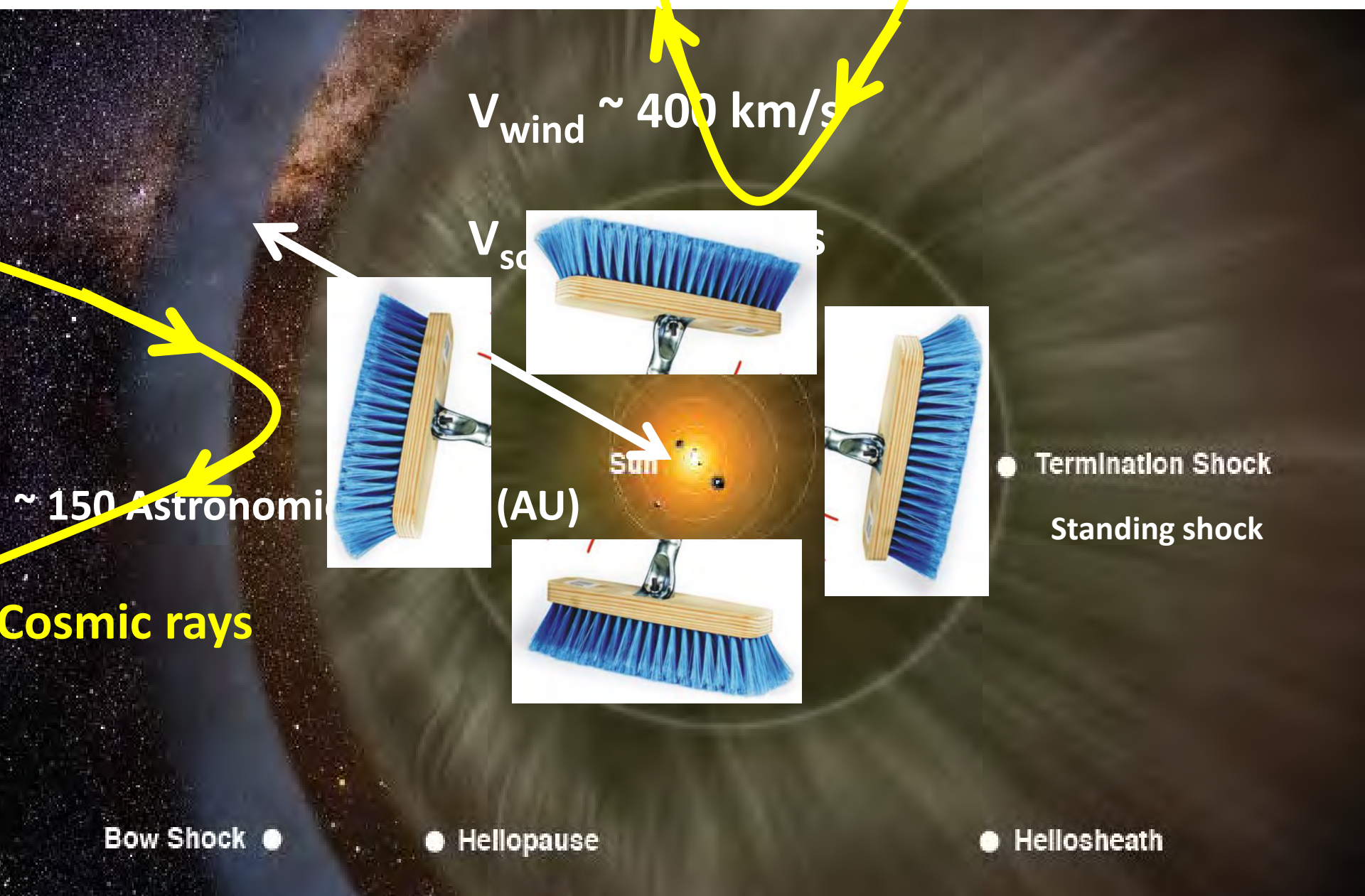
2000/02/27 01:54

# The Solar Wind and Heliosphere





# The (variable) broom



$V_{\text{wind}} \sim 400 \text{ km/s}$

$V_{\text{sc}}$



Sun

(AU)



● Termination Shock  
Standing shock

● Bow Shock

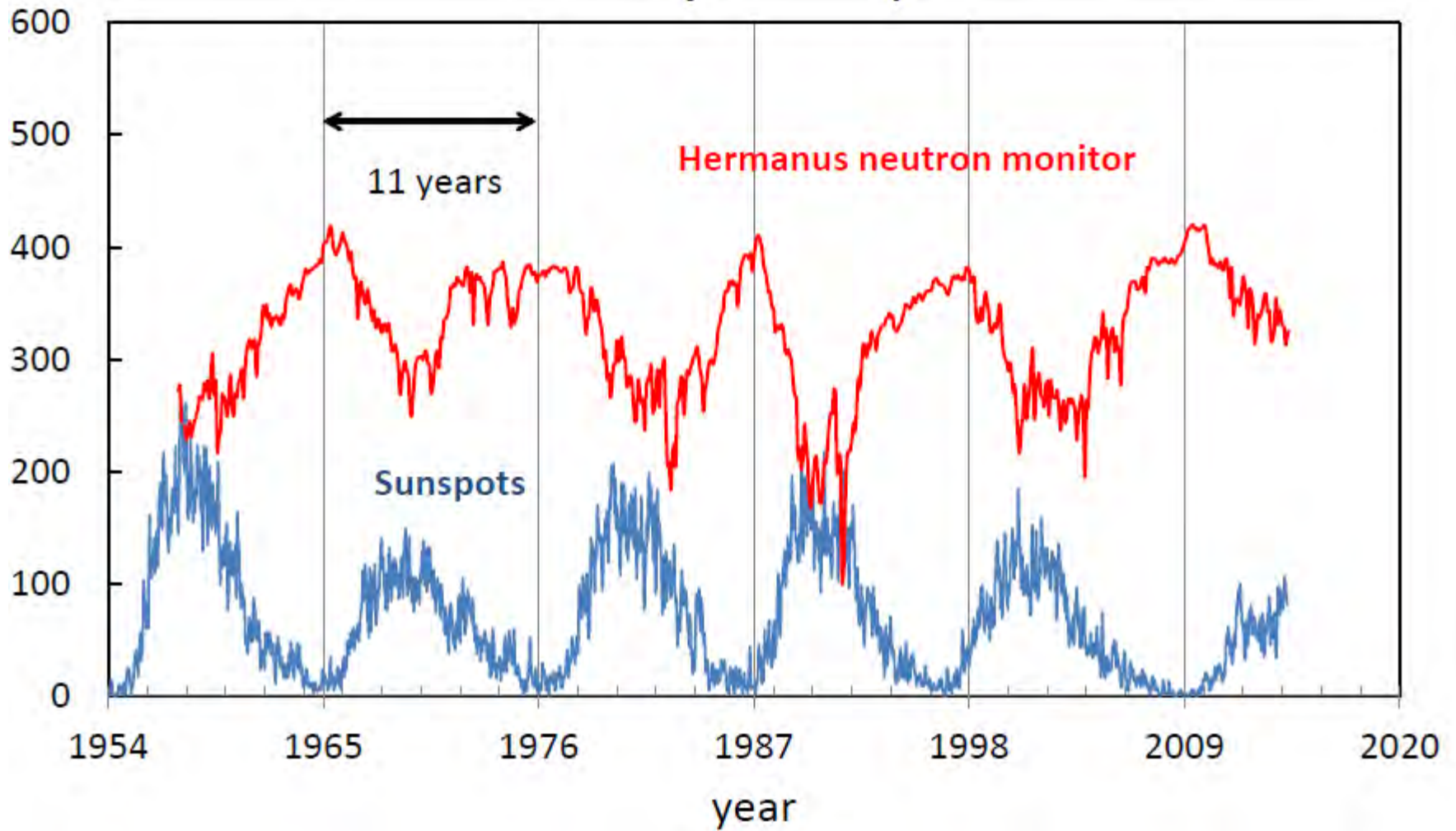
● Heliopause

● Heliopause

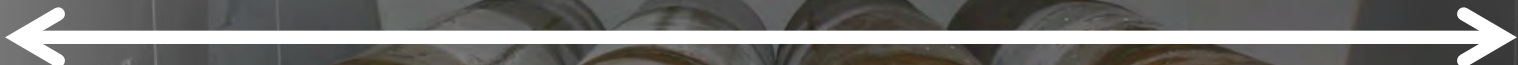
Cosmic rays

$\sim 150 \text{ Astronomical Units}$

# Cosmic rays and sunspots



# Sanae Neutron Monitor

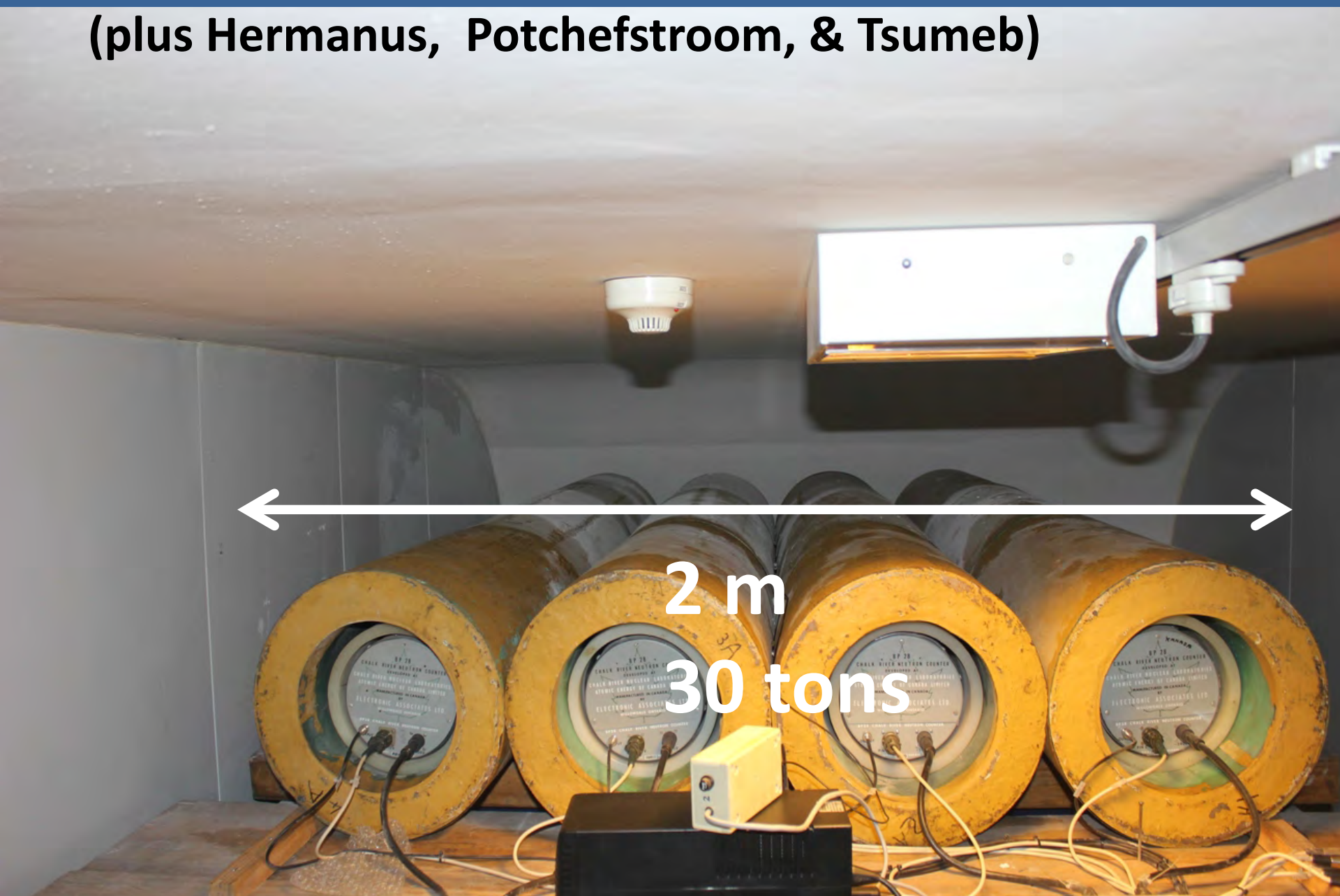


2 m

30 tons

# Sanae Neutron Monitor

(plus Hermanus, Potchefstroom, & Tsumeb)



# Mini neutron monitors



**Polarstern**



# Mini neutron monitors



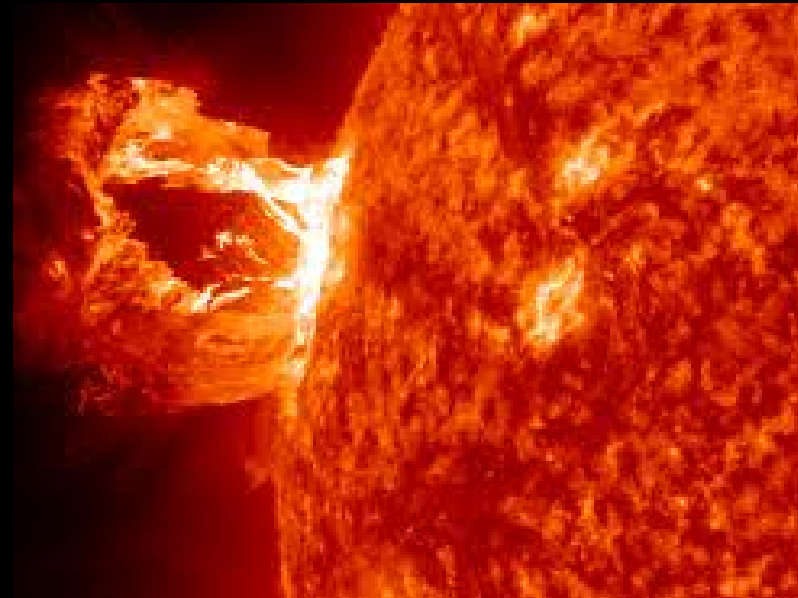
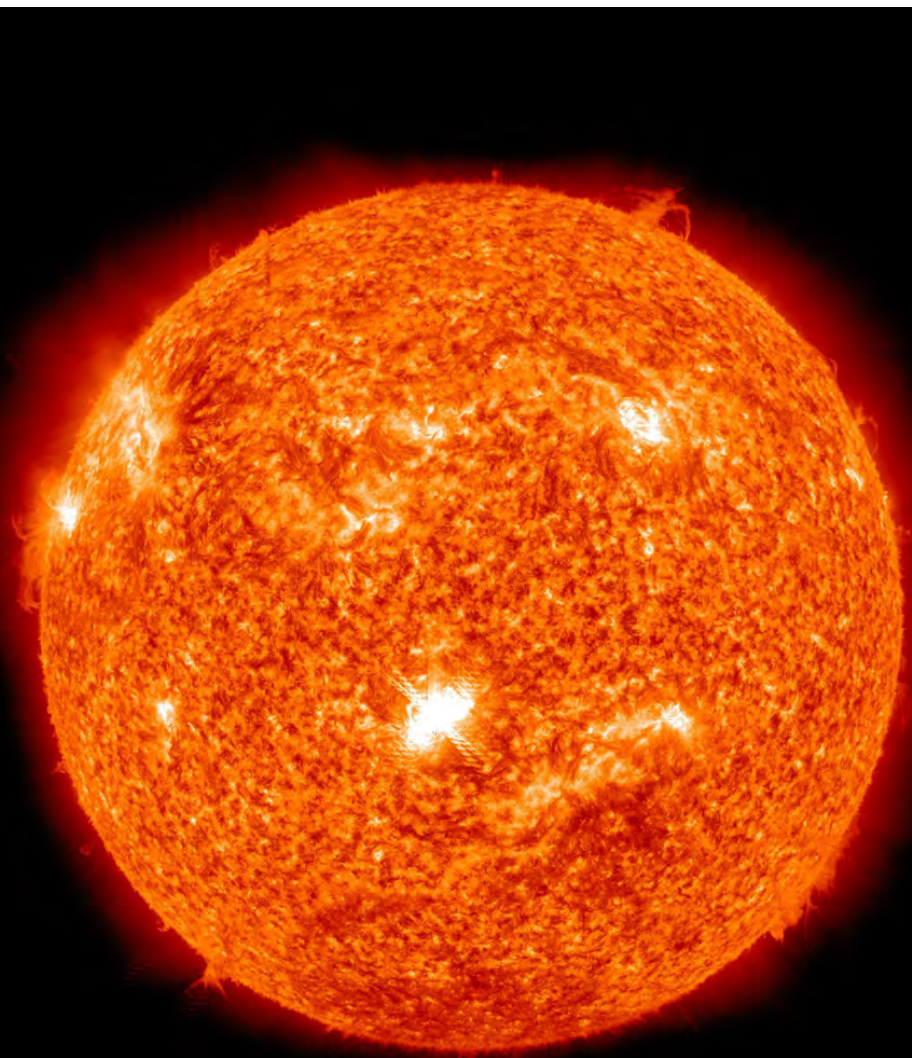
Polarstern



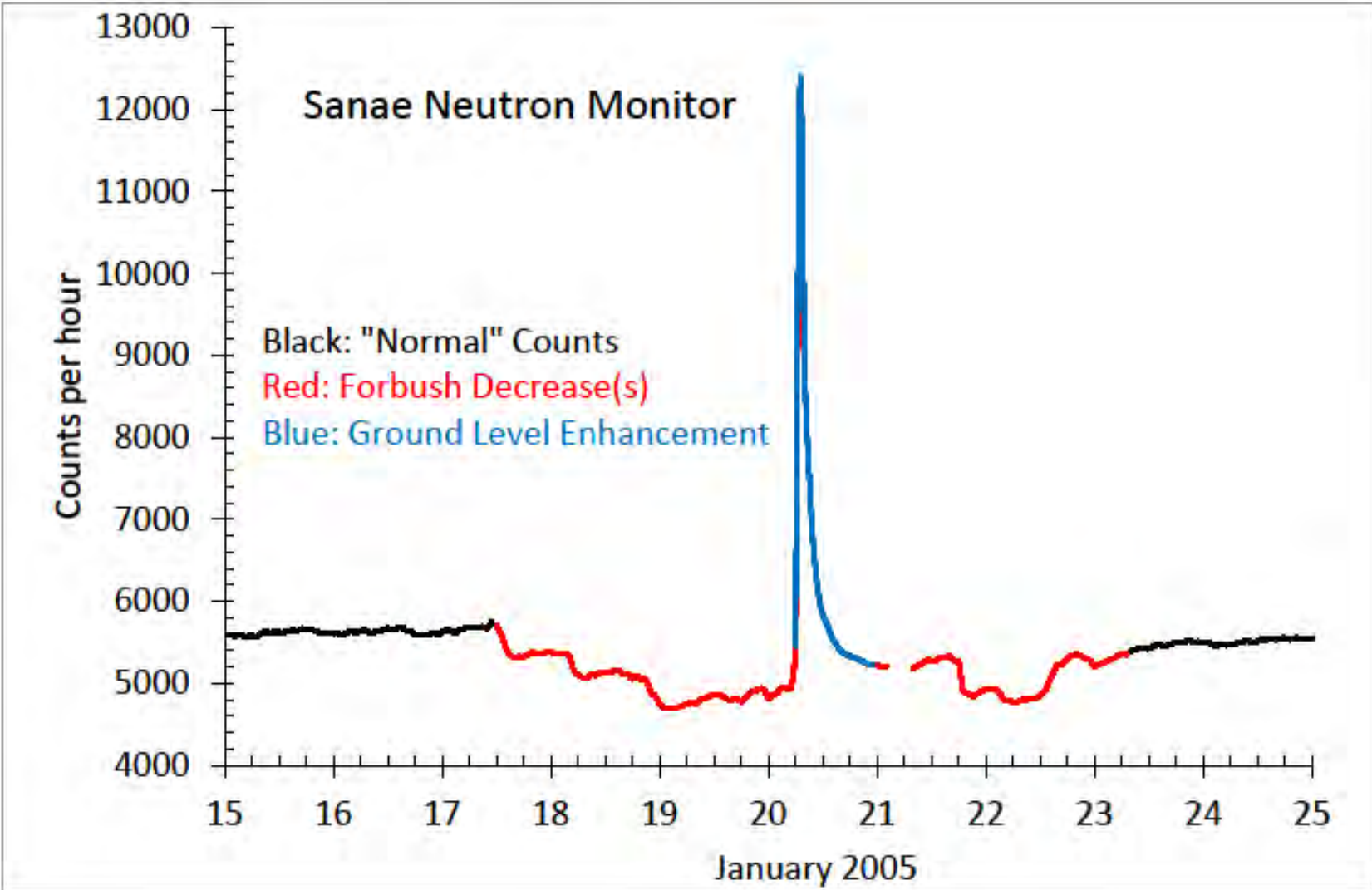
Posters  
Gert Benadé



# Solar Flare

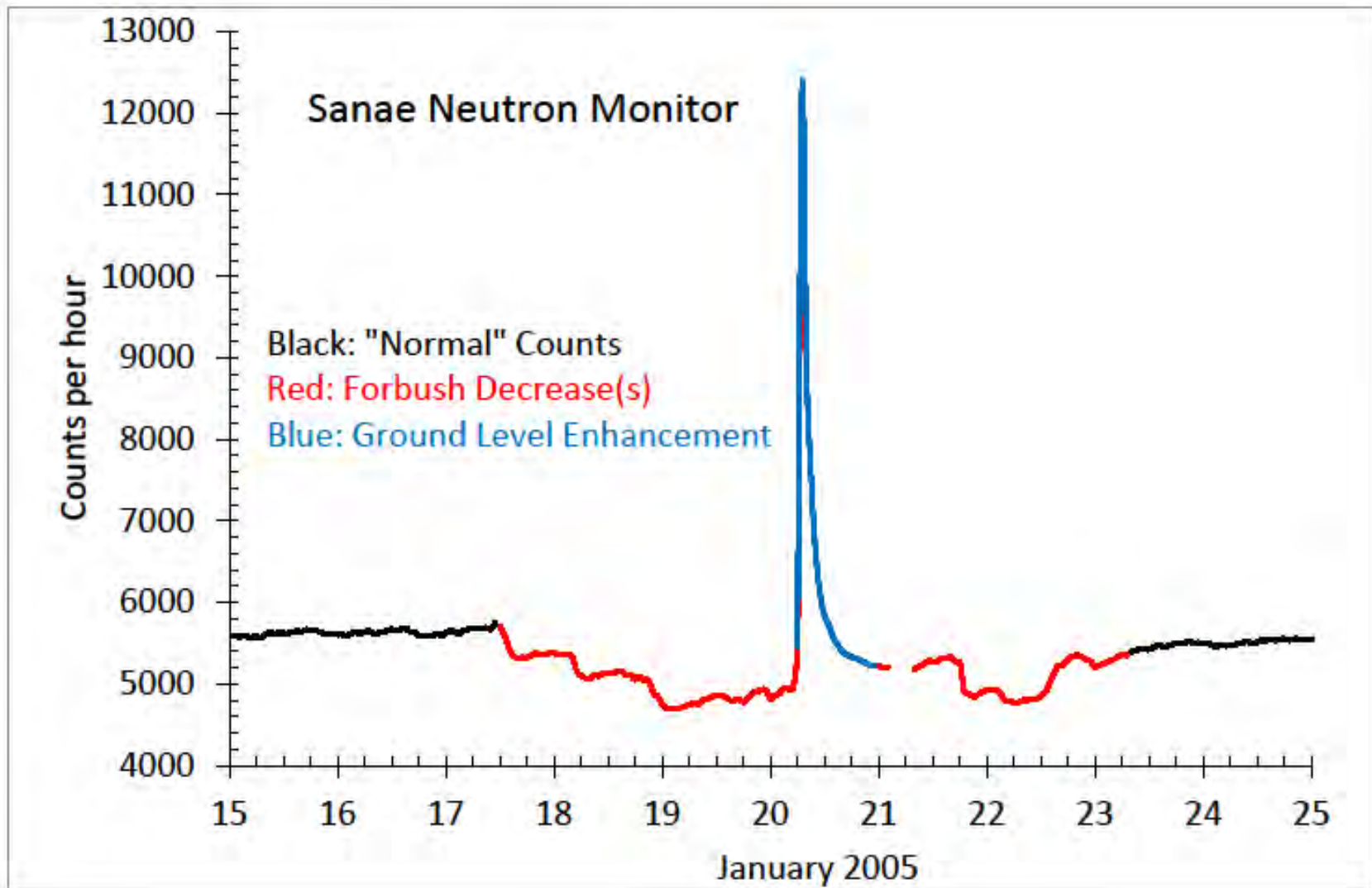


# Ground-level Enhancement (GLE) = "cosmic" rays from sun

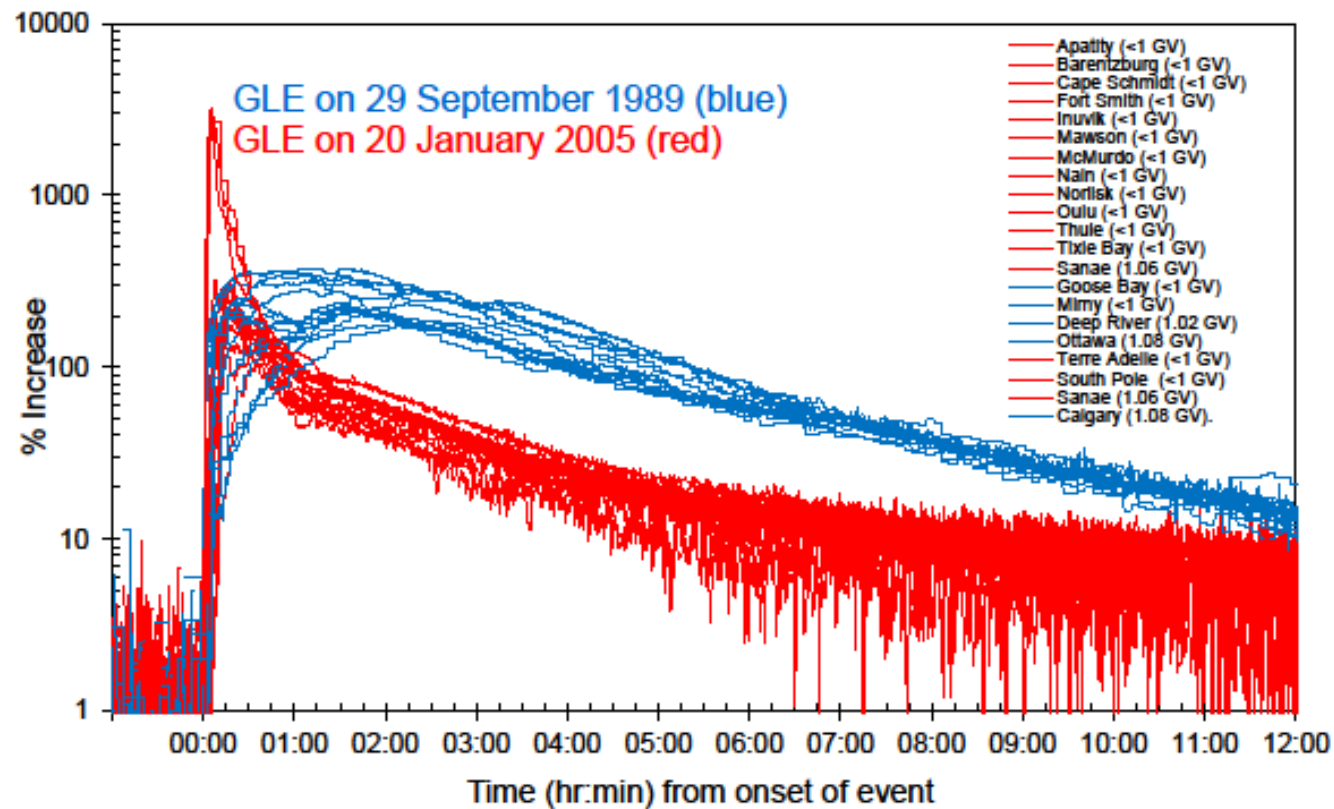




# Ground-level ~~Enhancement~~ Excitement (GLE)



# Two real big ones



# Why?

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- **Because it is there..... (academic)**
- **Appropriate Science and Technology**
- **Contribution to climate change**
- **Interdisciplinary (M.Sc. and M.Eng.)**

### Three forms of the Transport Equation

$$\frac{\partial U}{\partial t} + \nabla \cdot (\mathbf{V}U - \mathbf{K} \cdot \nabla U) - \frac{1}{3} (\nabla \cdot \mathbf{V}) \frac{\partial}{\partial p} (pU) = 0$$

or, in terms of  $f$

$$\frac{\partial f}{\partial t} + \nabla \cdot (\mathbf{V}f - \mathbf{K} \cdot \nabla f) - \frac{1}{3p^2} (\nabla \cdot \mathbf{V}) \frac{\partial}{\partial p} (p^3 f) = 0$$

or, slightly manipulated

$$\frac{\partial f}{\partial t} + \mathbf{V} \cdot \nabla f - \nabla \cdot (\mathbf{K} \cdot \nabla f) - \frac{1}{3p^2} (\nabla \cdot \mathbf{V}) \frac{\partial f}{\partial \ln p} = 0$$

Not changed for 45 years

Too difficult to solve analytically .....

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## Pre-2006 SANAP Mission

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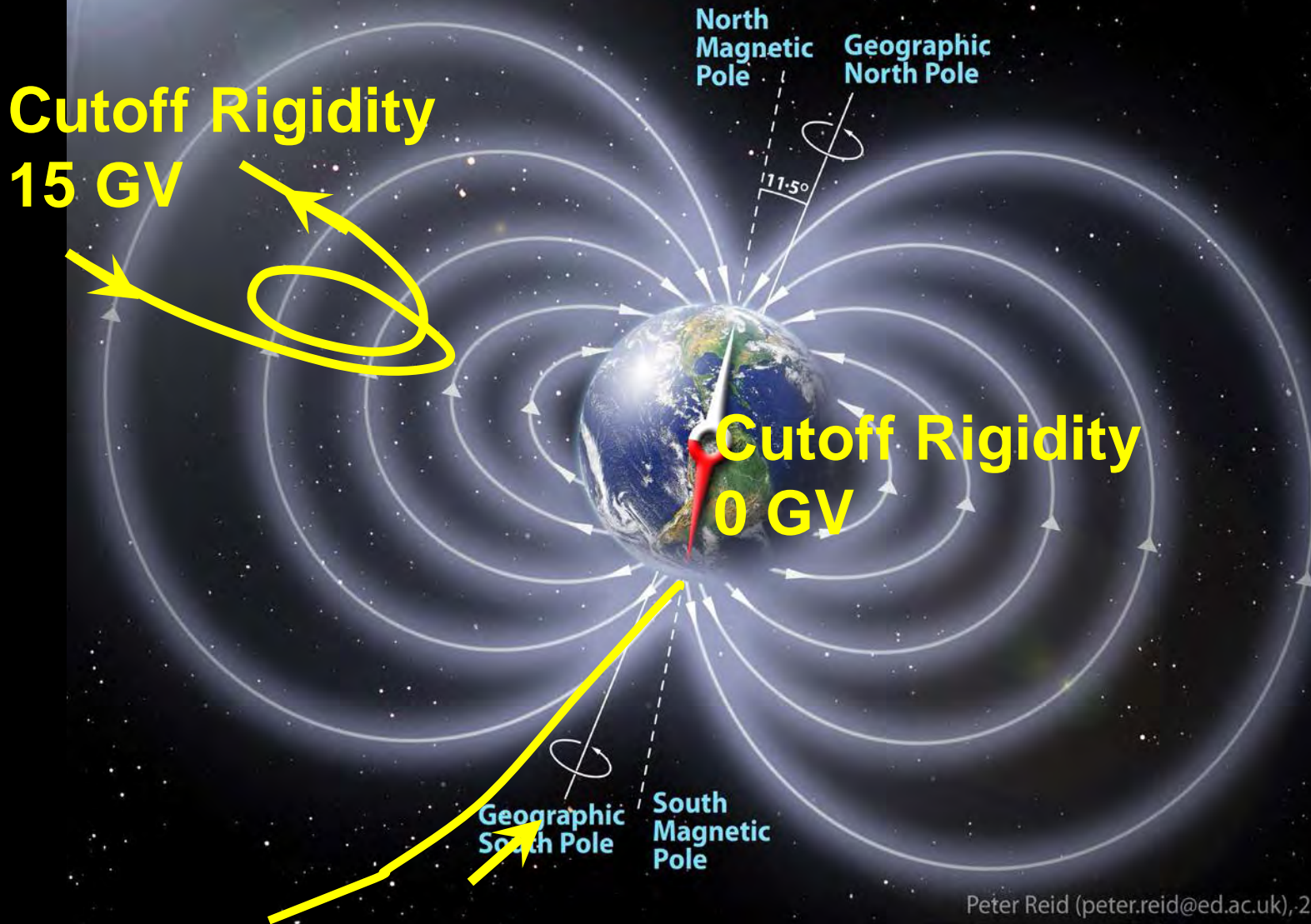
To increase understanding of the **natural environment** and **life** in the Antarctic and Southern Ocean through appropriate science and technology

## Pre-2006 SANAP Mission

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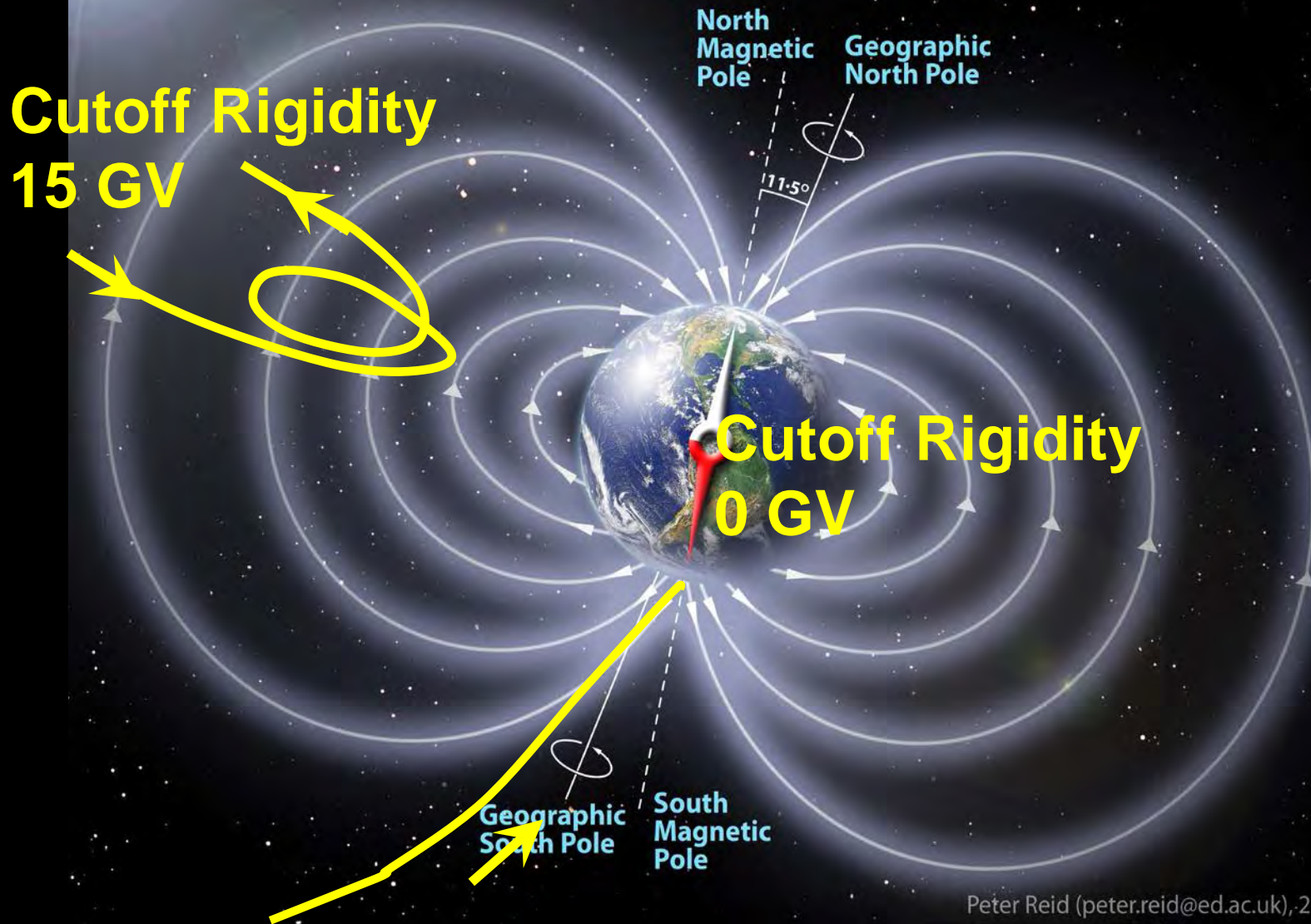
To increase understanding of the **natural environment** and **life** in the Antarctic and Southern Ocean through **APPROPRIATE** science and technology

# The poles are better

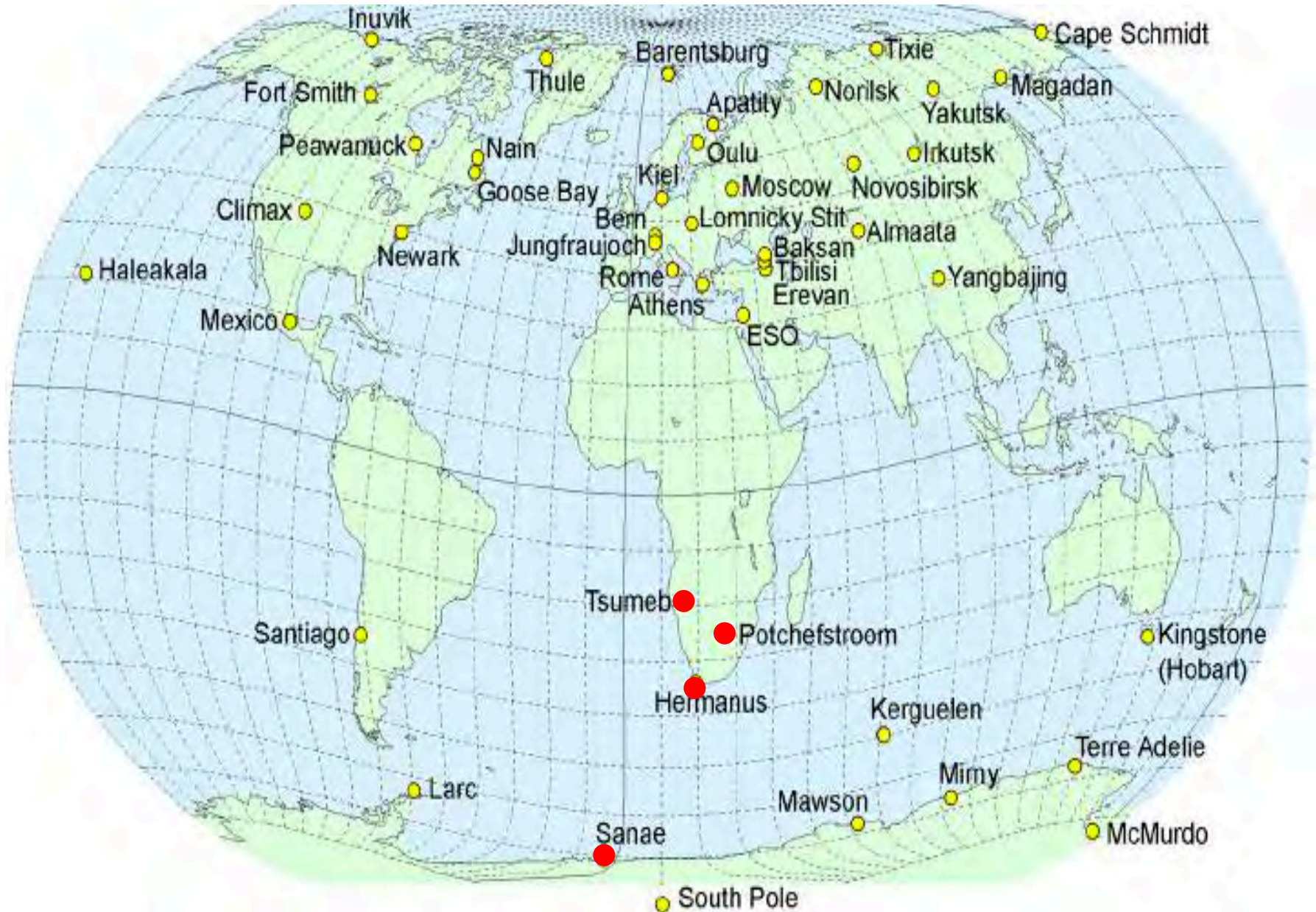




# The poles are better – a window into geospace



# Appropriate.....



## Appropriate.....

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- **One space mission > \$ 70 M = R 700 M**
  
- **Neutron monitors = R 250 K per year x 40 NMs**  
**x 60 years = R 600 M**

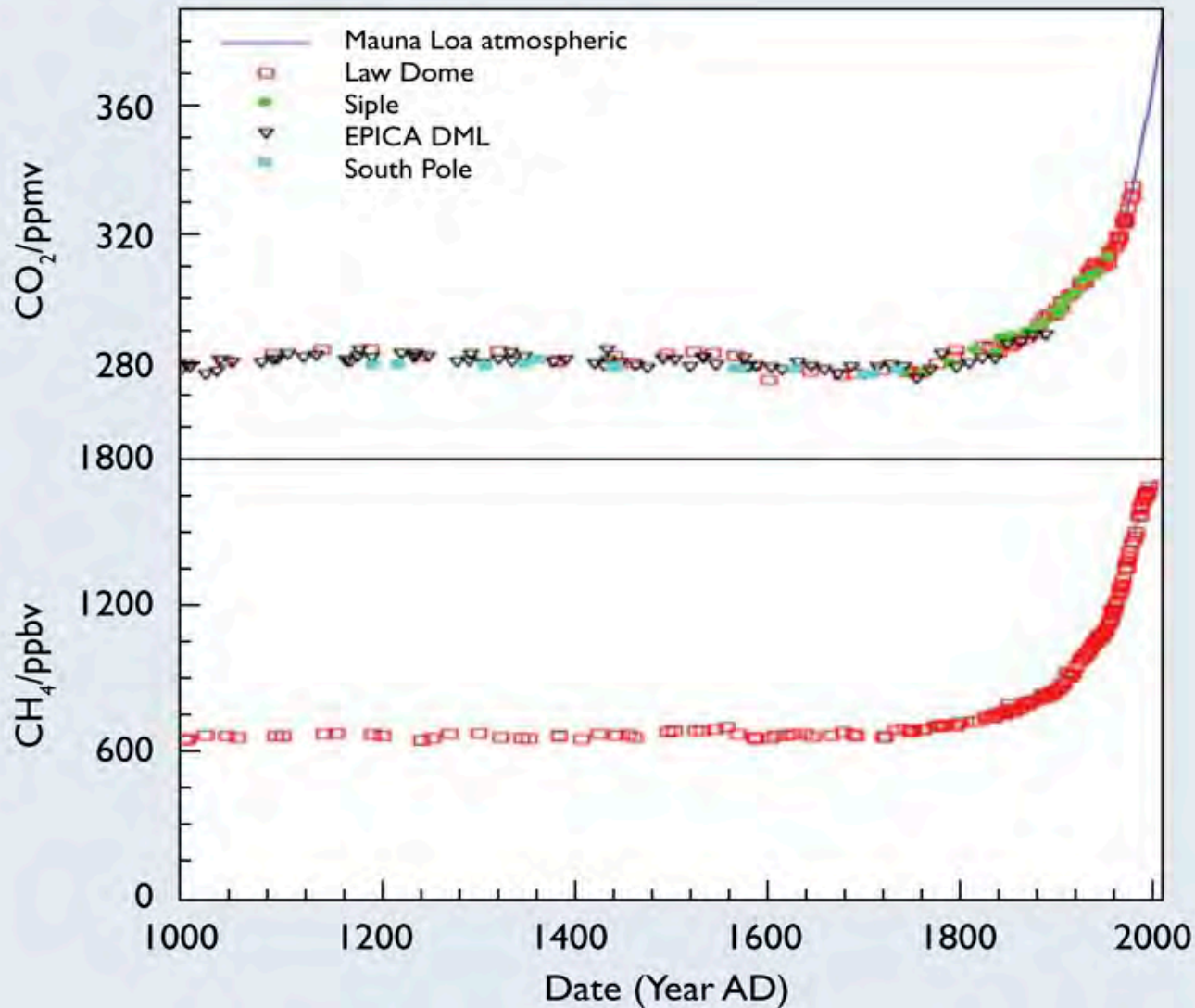
# Why?

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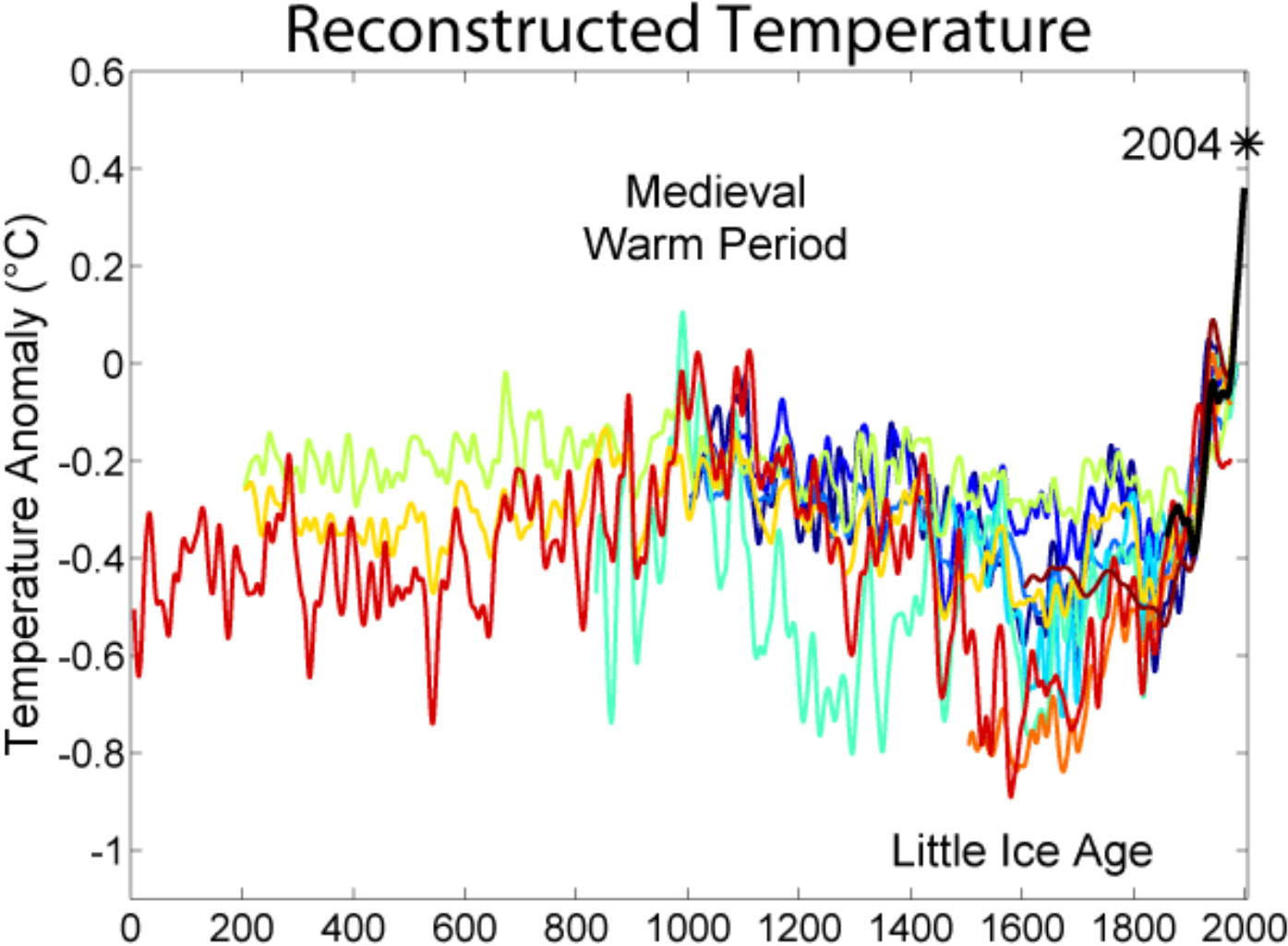
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# Climate change

Fig. 2:  $\text{CO}_2$  and  $\text{CH}_4$  over the last 1,000 years<sup>(1-4)</sup>

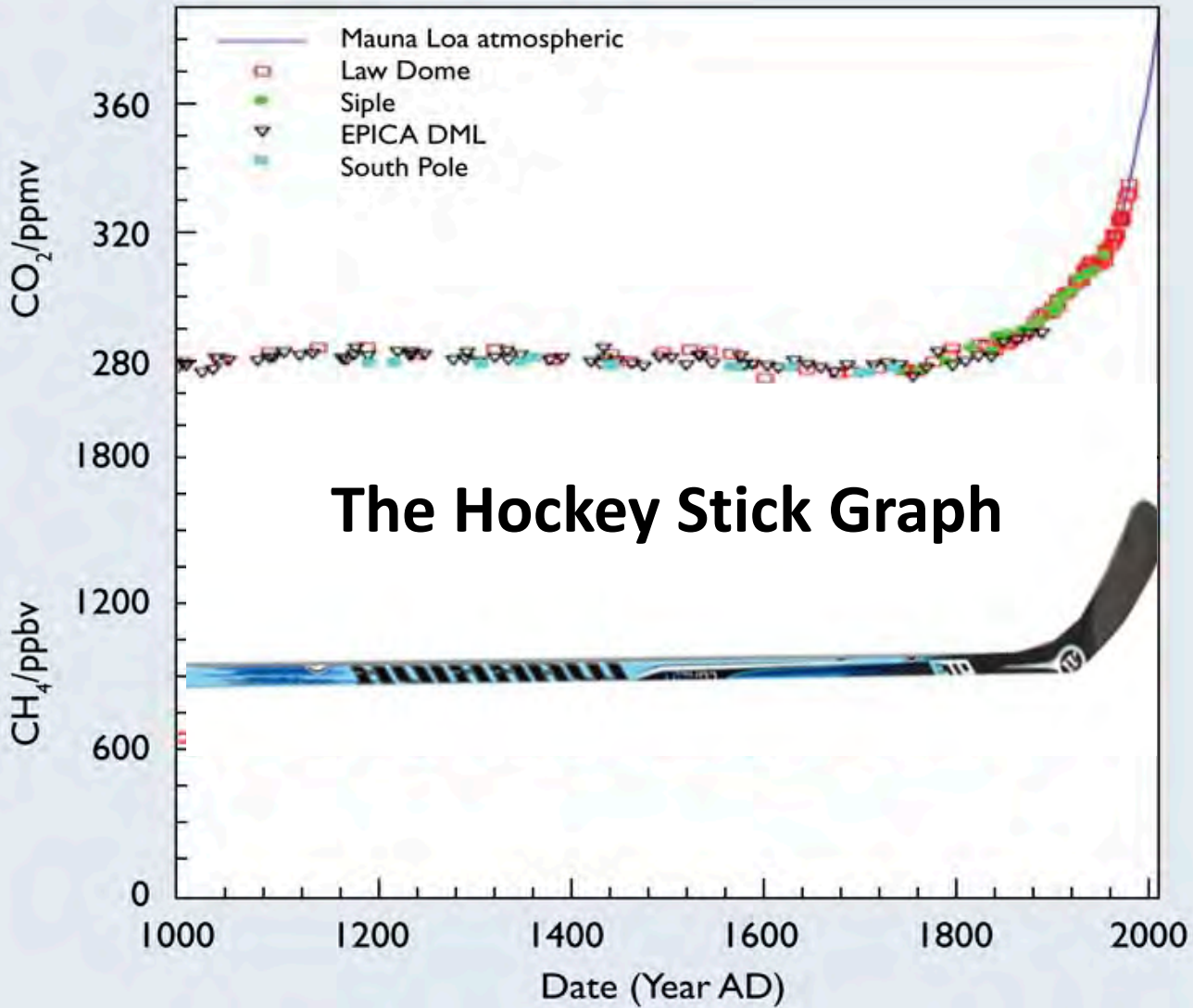


# Climate change



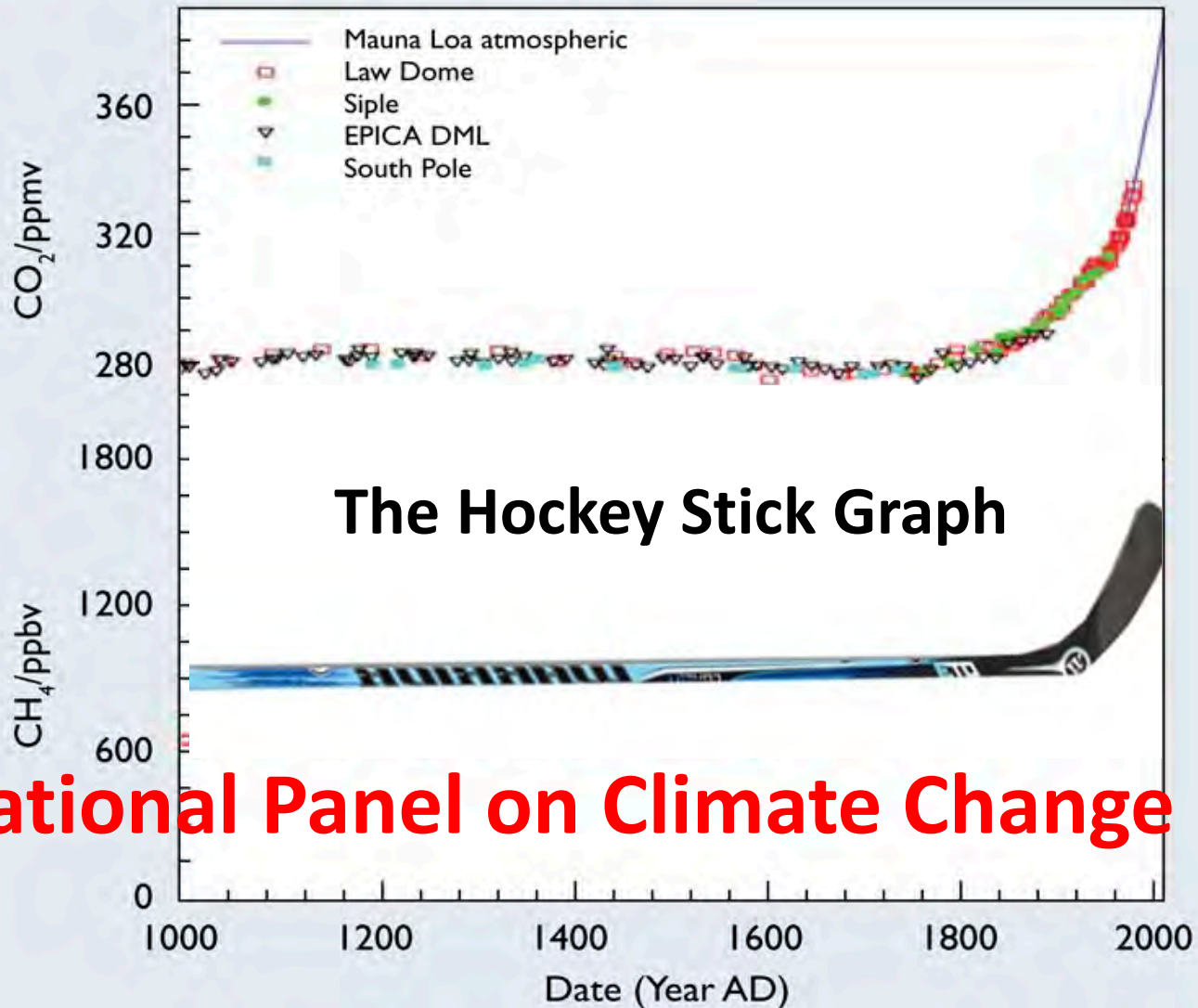
# Climate change

Fig. 2: CO<sub>2</sub> and CH<sub>4</sub> over the last 1,000 years<sup>(1-4)</sup>



# Climate change

Fig. 2:  $\text{CO}_2$  and  $\text{CH}_4$  over the last 1,000 years<sup>(1-4)</sup>

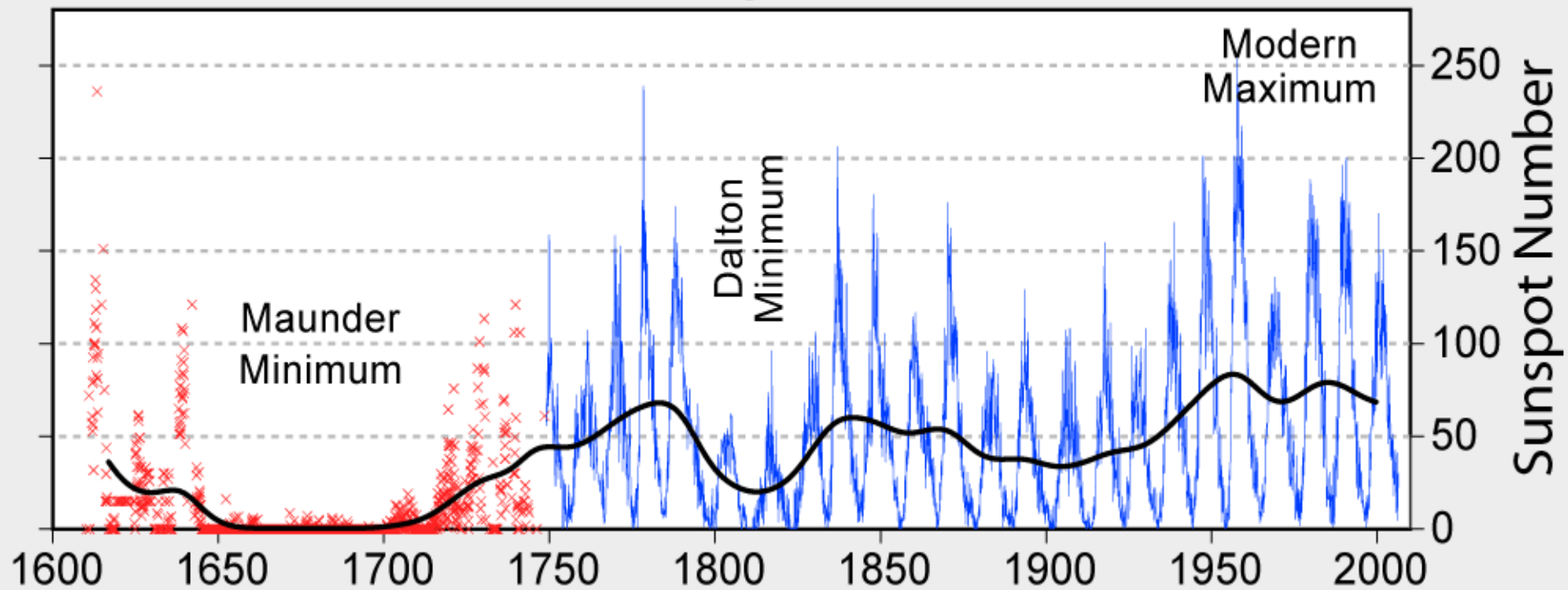


**International Panel on Climate Change (IPCC)**



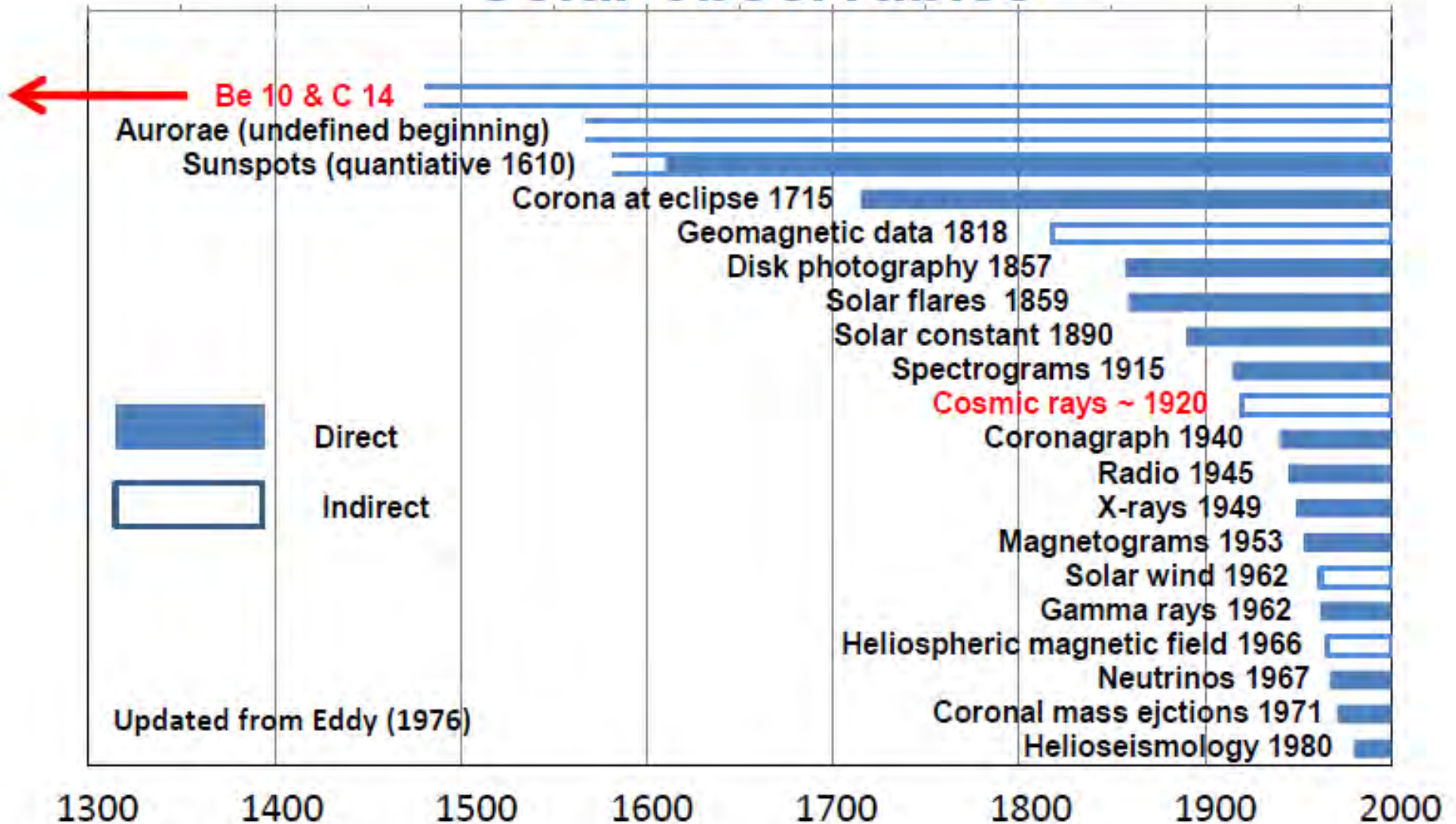
# Climate change

## 400 Years of Sunspot Observations

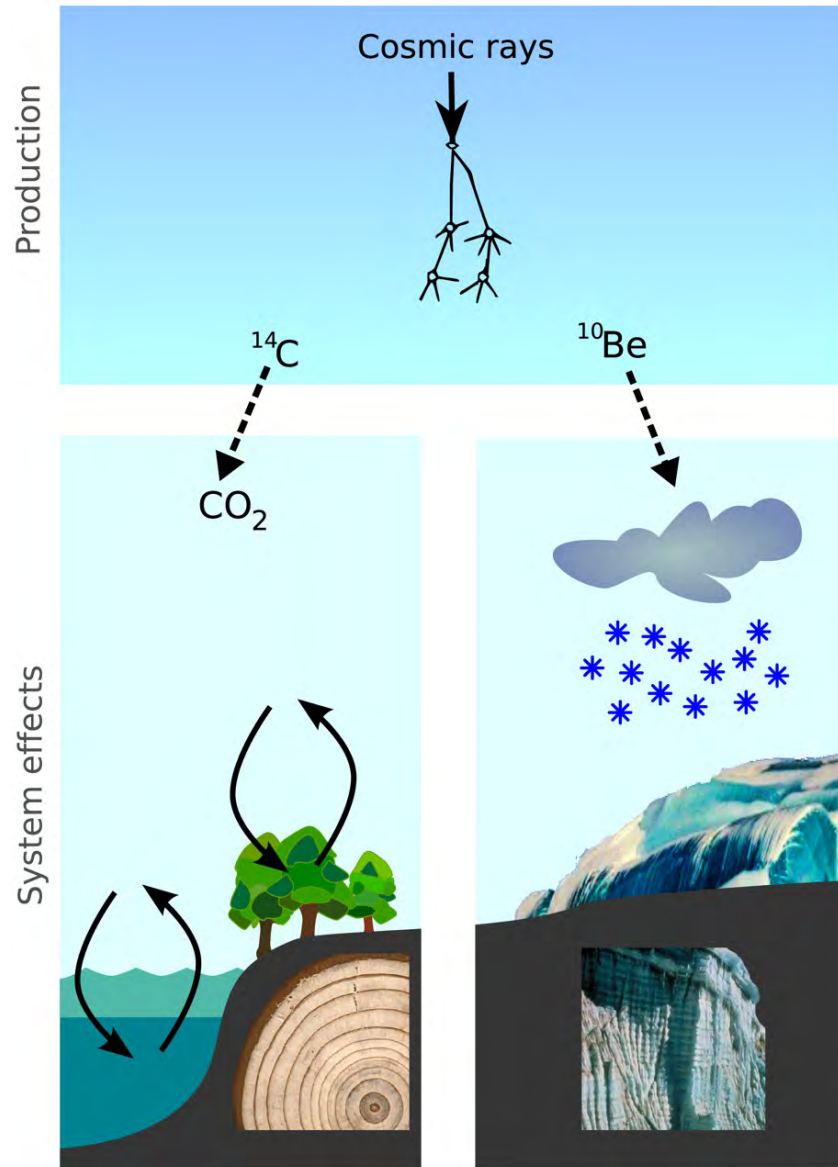


# History of the Sun

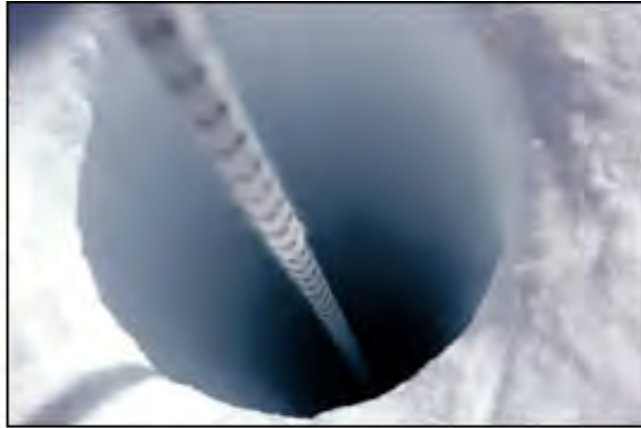
## Solar observables



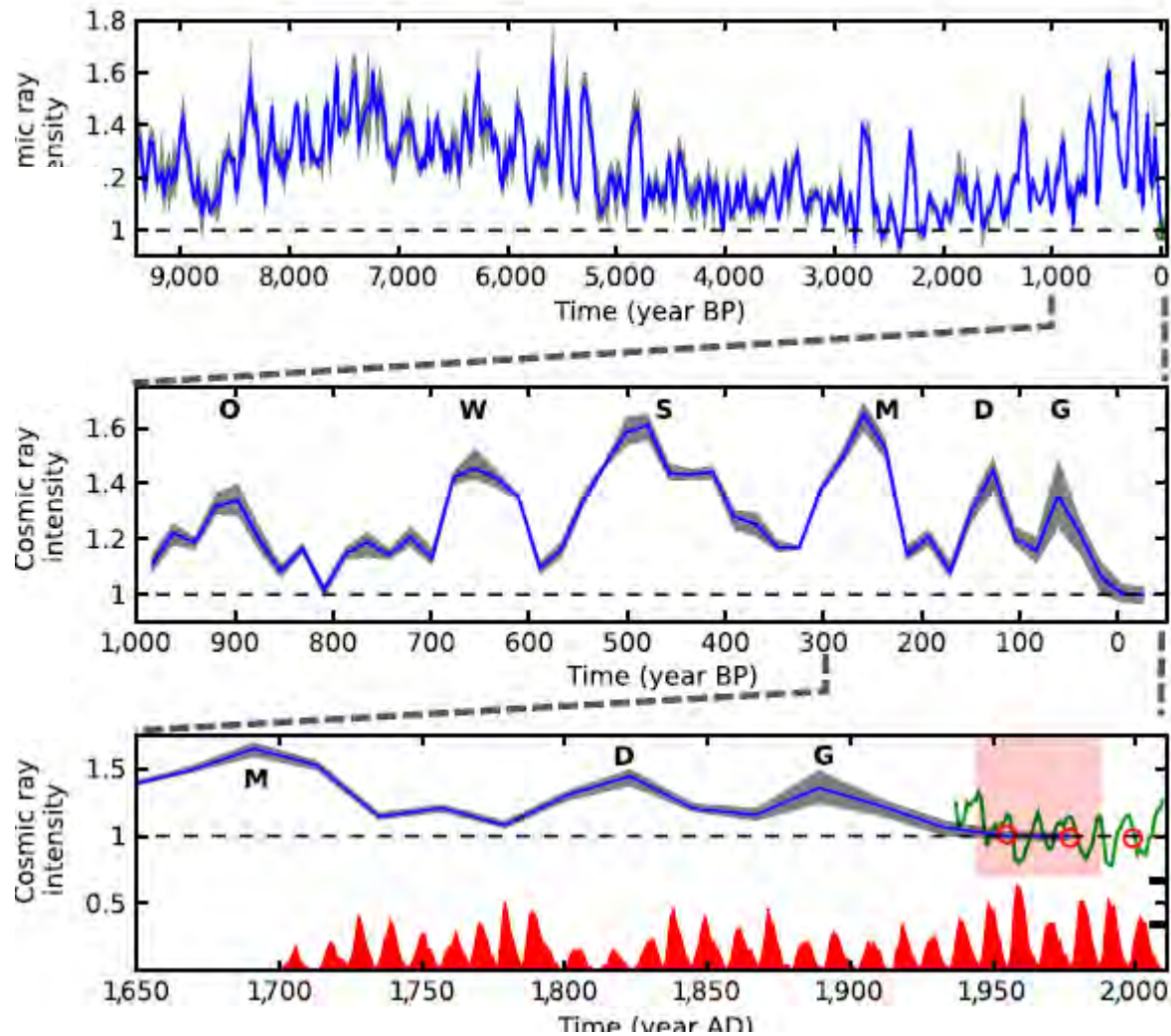
# Paleo-cosmic rays: $^{14}\text{C}$ and $^{10}\text{Be}$



# Paleo-cosmic rays: $^{10}\text{Be}$

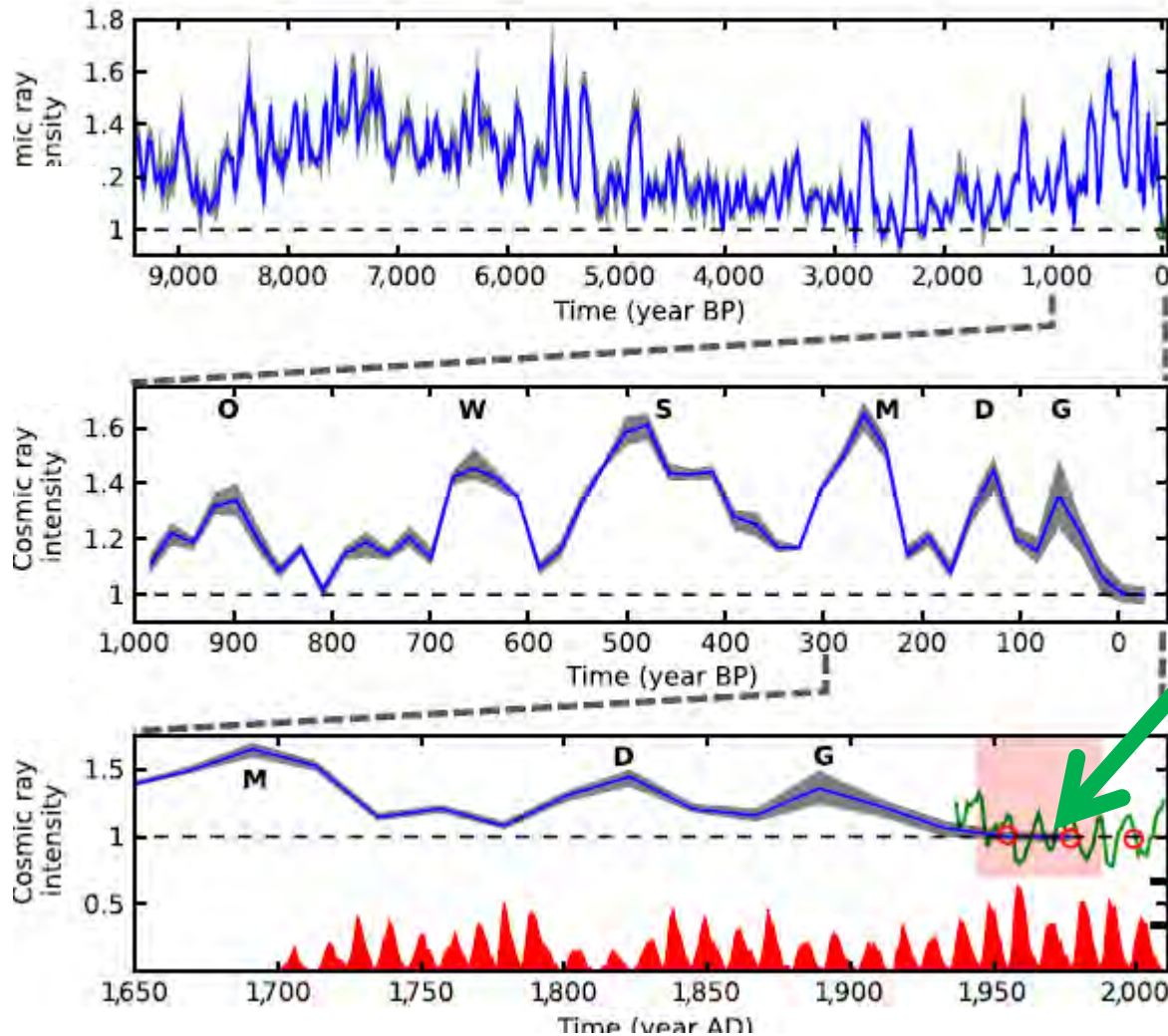


# $^{10}\text{Be}$ in polar ice ... Earth's neutron monitor



Steinhilber et al. (2012)

# $^{10}\text{Be}$ in polar ice ... Earth's neutron monitor



Real  
neutron  
monitor

Steinhilber et al. (2012)

# Ice shelf in Queen Maud Land

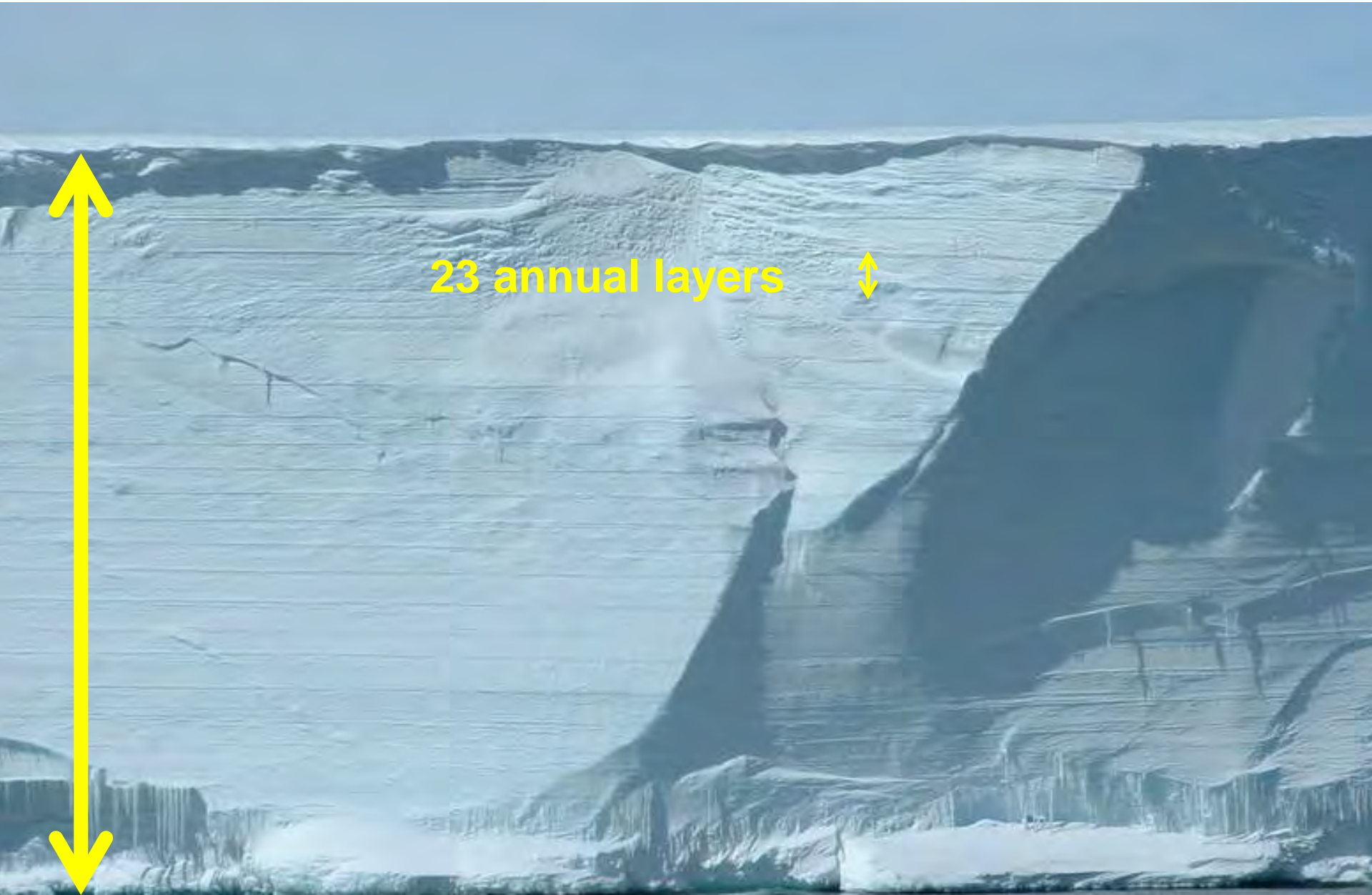


# Ice shelf in Queen Maud Land



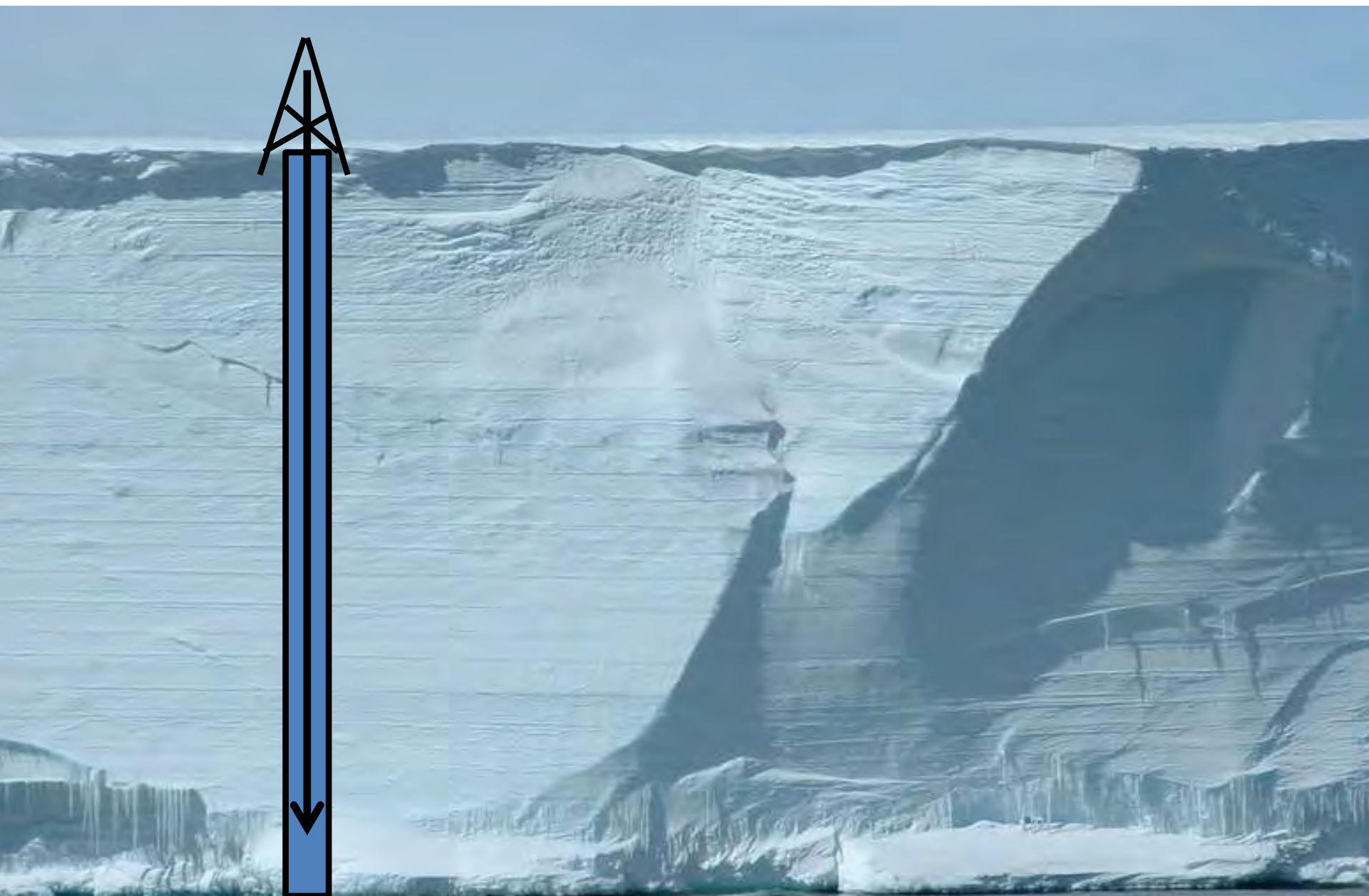


# Ice shelf in Queen Maud Land



23 annual layers

# Shallow drilling ..... 60 years deep

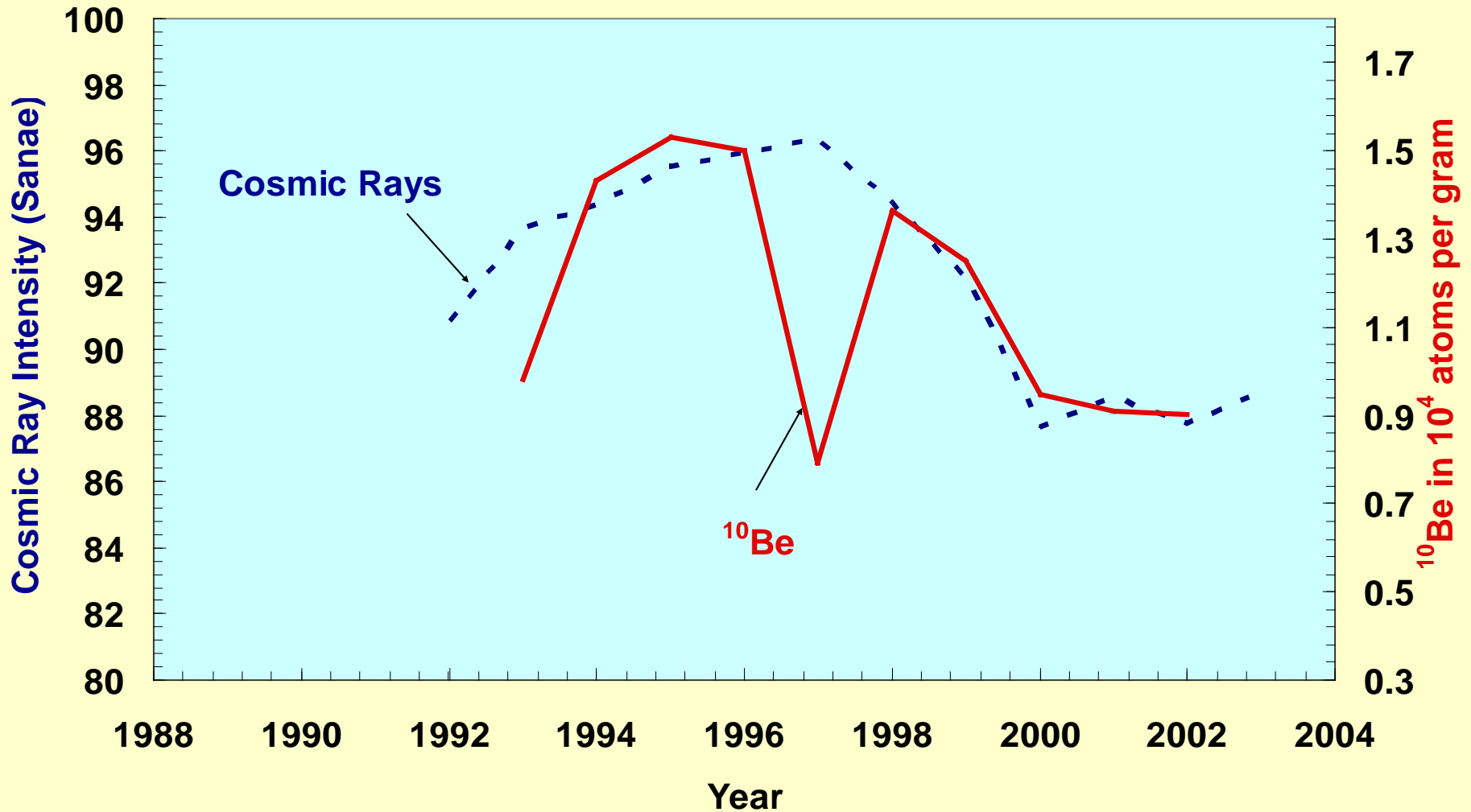


# Pilot Project 2006



# Pilot project 2006

## $^{10}\text{Be}$ and Cosmic Rays



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**Thank you:**

**NRF/DST**

**DEA**

**Rhodes University Organisers**

# Cosmic-ray spectrum

