# Cosmogenic nuclide production by radiation from supernovae

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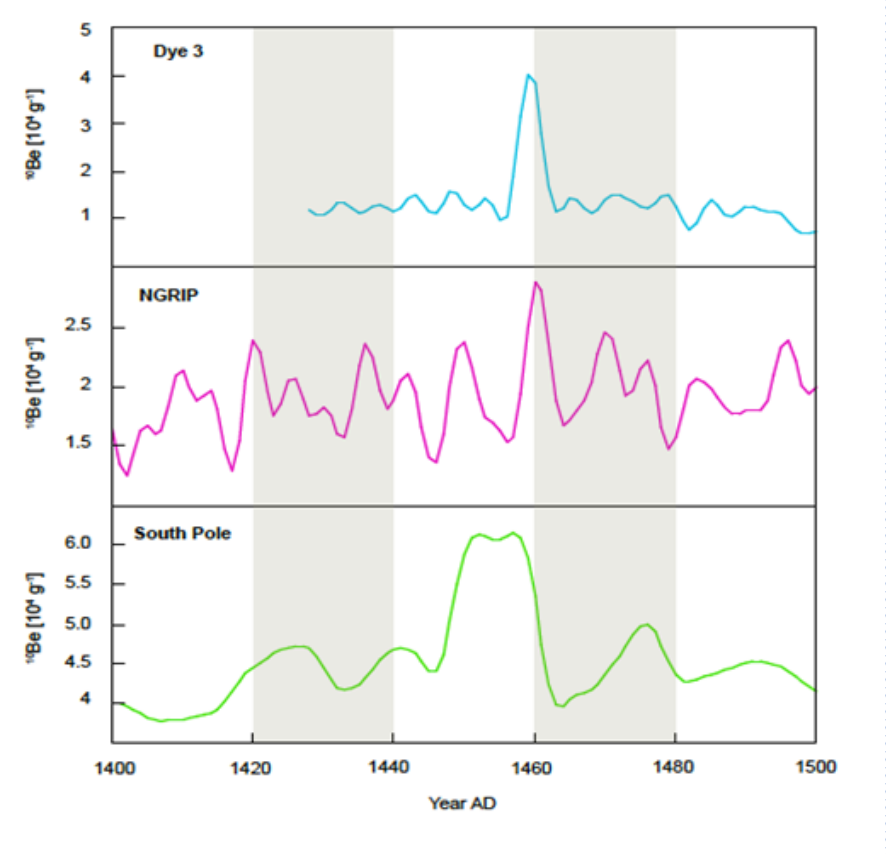
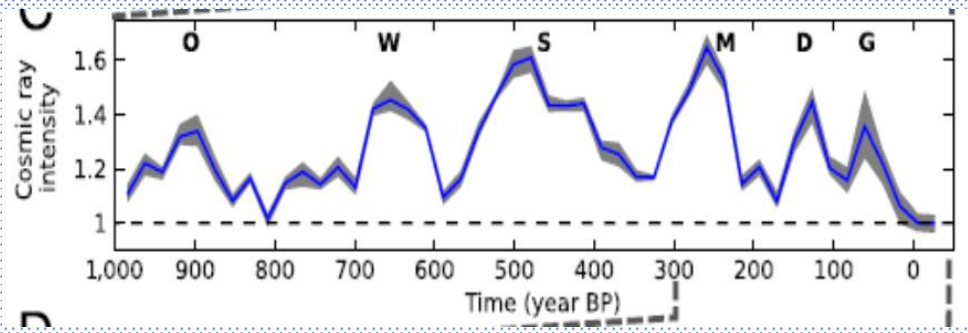
**August 28, 2023**

**TAUP 2023, Vienna**

# $^{10}$Be flux observed at Dye 3, North GRIP in Greenland, and at the South Pole and Dome Fuji in Antarctica.




The 22 year average paleocosmic ray intensity for the period 950-1975 AD(8) .

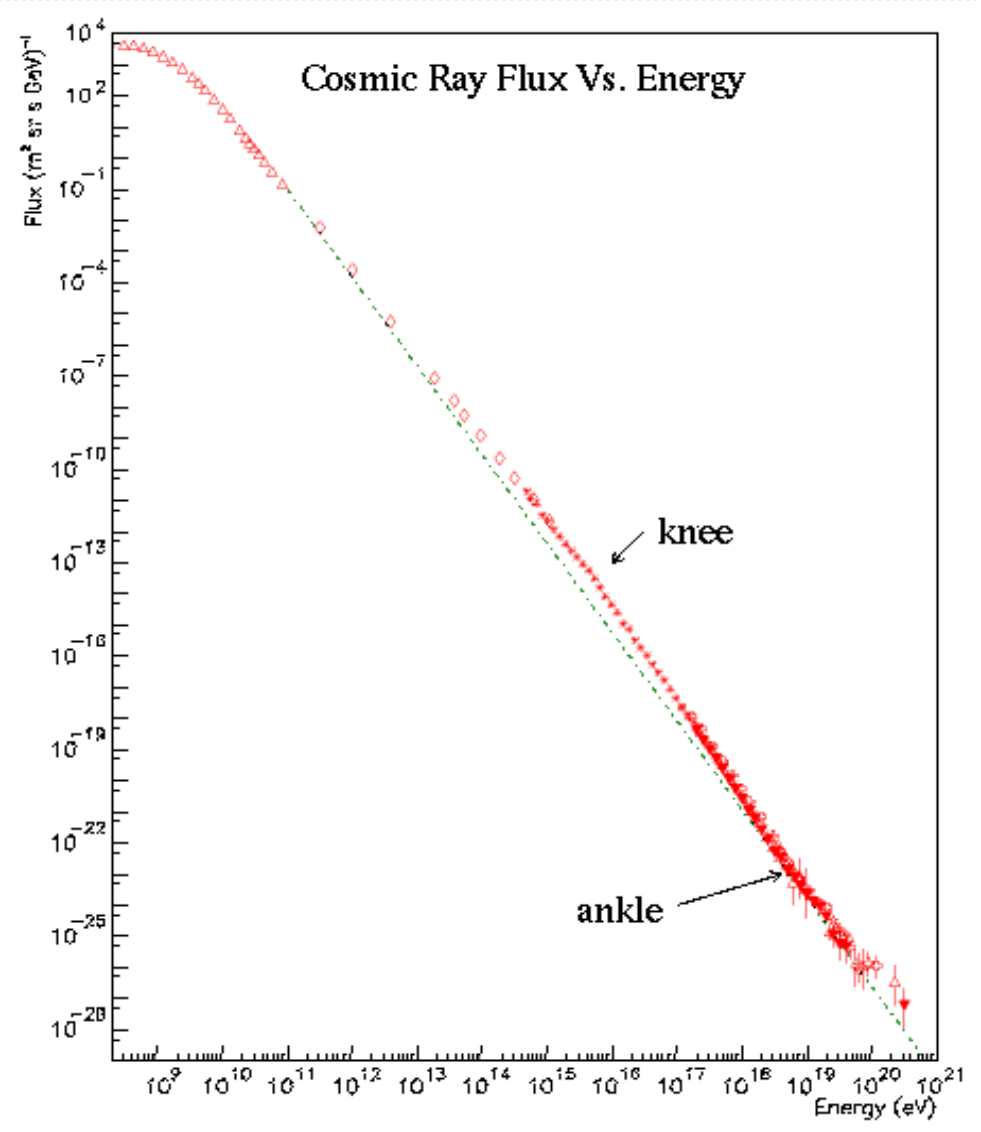


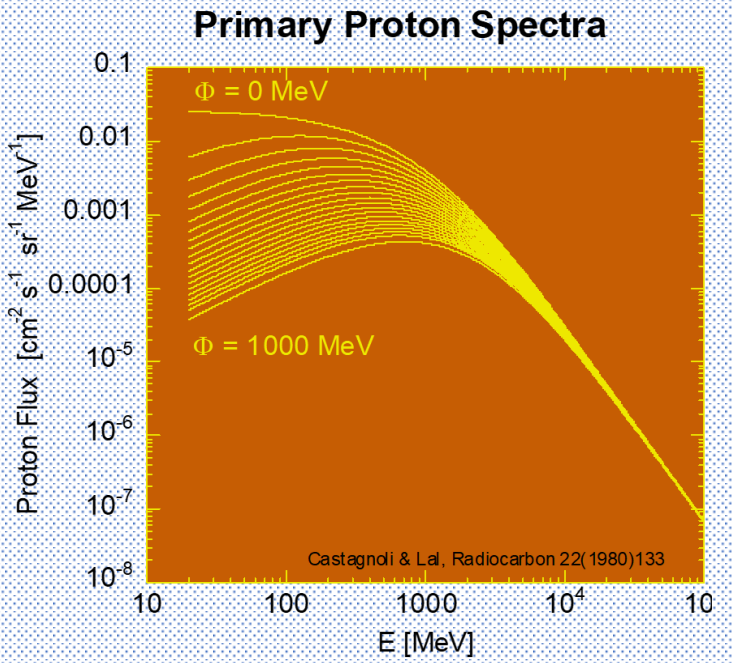

**This indicates that the solar conditions during the Spoerer (S) Minimum were similar. That is, the enhancements in 1460 occurred during an interval of very low solar activity.**

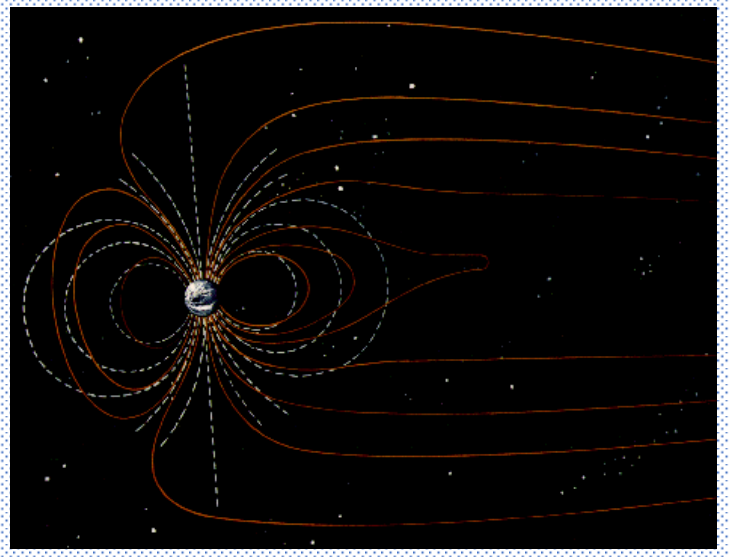
## Particle fluxes calculated with Monte Carlo Codes

- Interactions of GCR and γ-rays with Earth atmosphere and production of secondary particles were simulated with GEANT 4/ MCNP code system
- The atmosphere was irradiated by a flux of GCR protons or γ-rays
- From the fitting of experimental measurements of cosmogenic nuclide production rates in the Moon the effective primary-particle flux above 10 MeV was determined to be 4.56 p $cm^{-2}s^{-1}$. Flux of γ-rays has to be determined
- Differential neutron and proton fluxes $J_n(E,d)$ for energy range $10^{-9}$- $10^{6}$ MeV were calculated for specific depth d.

# GCR primary spectra



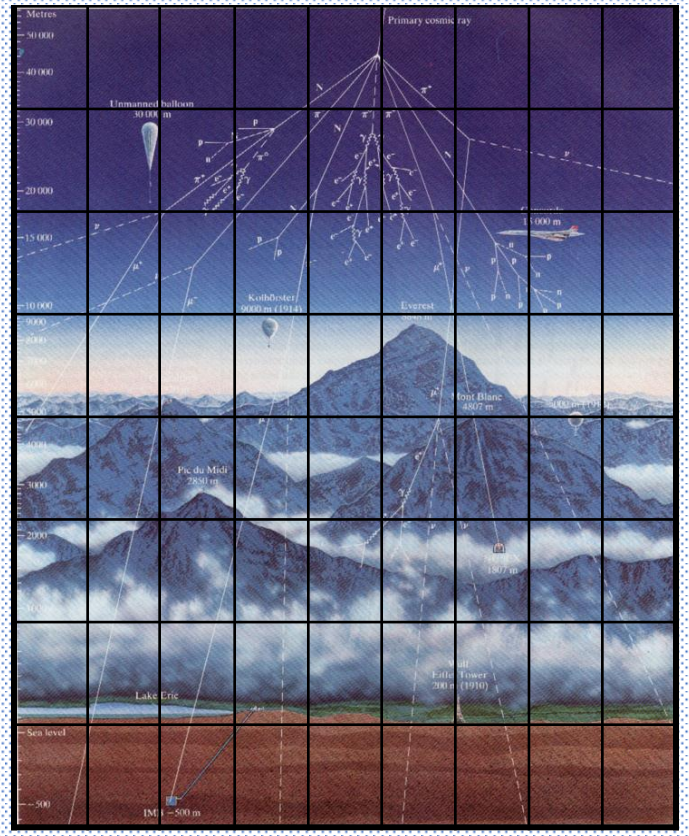



# Production rate (P) calculation

- Use fluxes $J_n$ calculated by GEANT4 / MCNP for depth d in the irradiated object

# Simulation of Cosmic Ray Secondaries in the Atmosphere

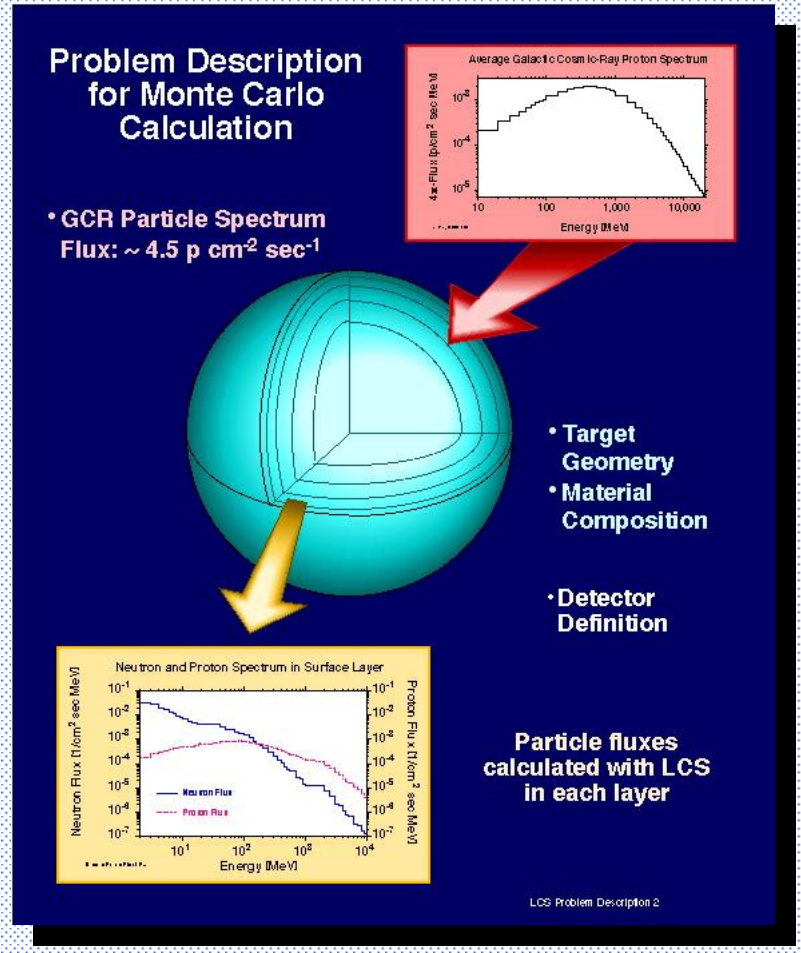



Latitude:

9 bins of 10 degrees

Depth:

34 layers of 30 g/cm$^2$



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# Chemical compositions and density

| Element | Soil | Atmosphere |
|---|---|---|
| H | 0.002 | |
| N | | 0.78 |
| O | 0.473 | 0.21 |
| Na | 0.025 | |
| Mg | 0.040 | |
| Al | 0.060 | |
| Si | 0.280 | |
| Ar | | 0.01 |
| Ca | 0.050 | |
| Fe | 0.060 | |

**Atmospheric density in $g/cm^{-3}$**

- $\rho = 1.27 \times 10^{-3} e^{-109h}$ for $h \leq 9.73$ km
- $\rho = 2.03 \times 10^{-3} e^{-157h}$ for $h > 9.73$ km

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- Use detailed library of neutron-capture cross sections in MCNP or experimental and evaluated cross sections for spallogenic products

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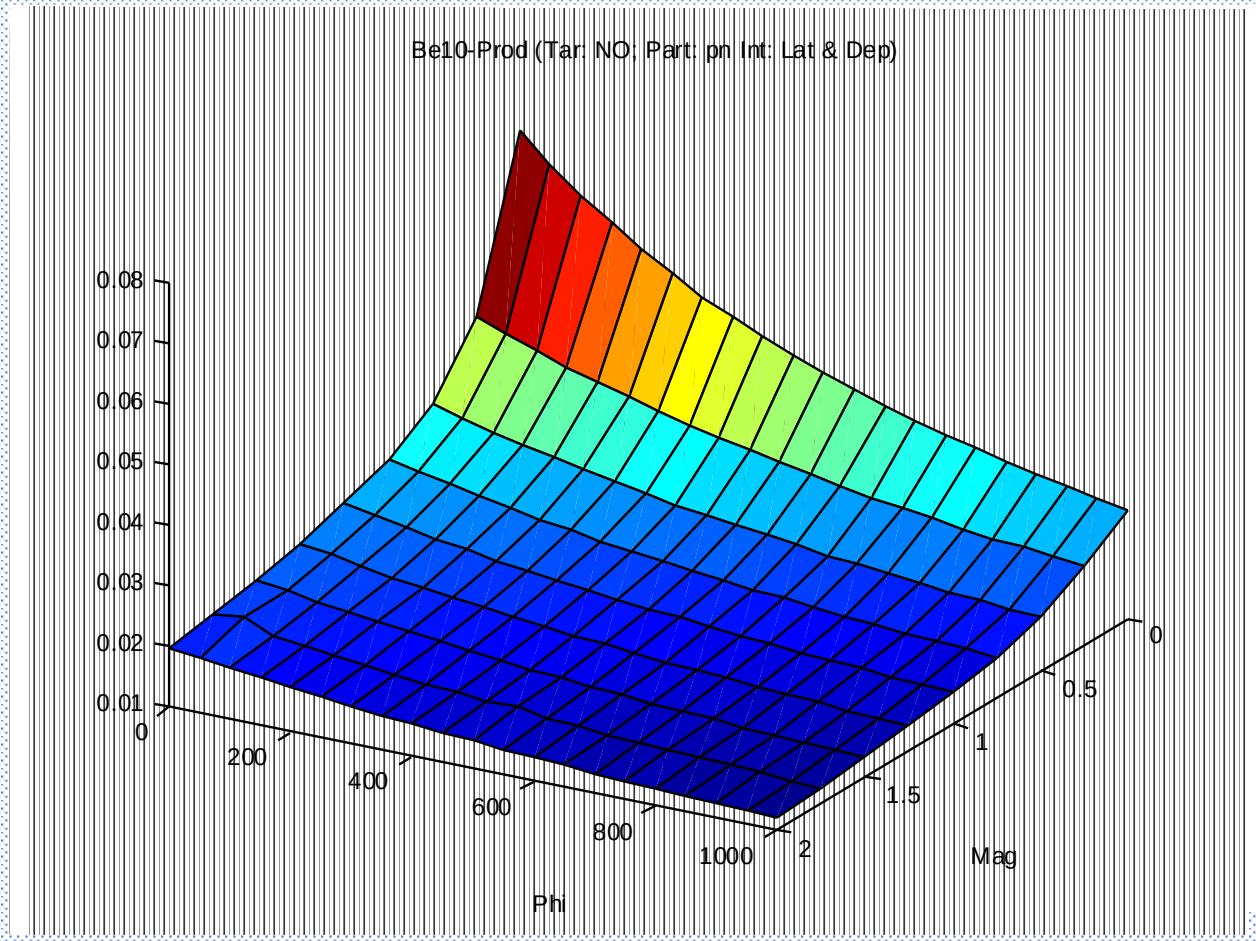
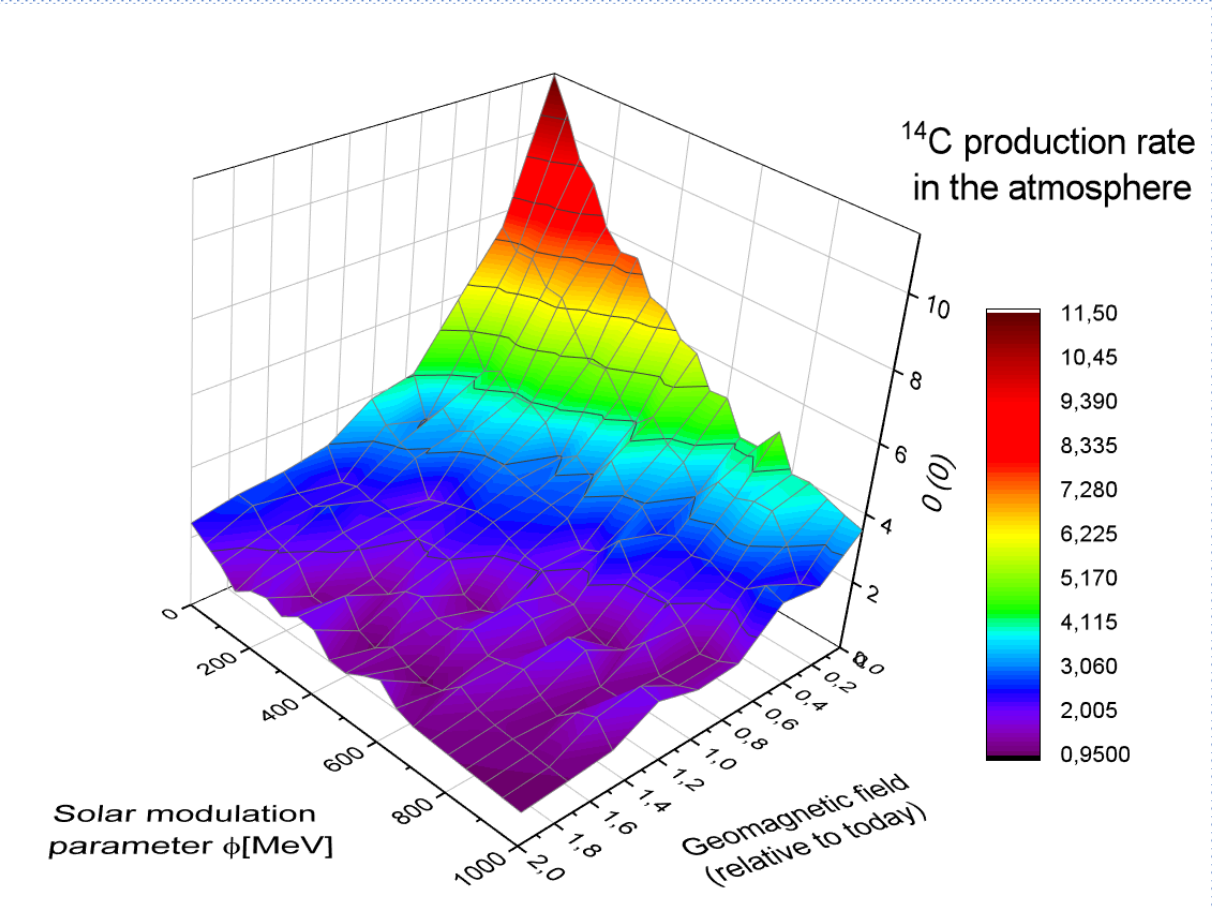
- Integrate fluxes times cross sections ($\sigma$) over energy E

$$P(R,d) = \sum_i N_i \int_0^\infty \sigma_{ijk}(E_k) J_j(E_k, d) dE_k$$

# Dependence of $^{10}$Be production on solar modulation and magn. field



# Possible explanations of observed enhancements

The very low probability of chance occurrence, the excursion above $^{10}$Be(LIS), and the one year duration in the Greenland data indicates that the **$^{10}$Be enhancements were not produced by the GCR.**

We conclude that they were **due to an additional, short lived source of cosmic radiation.**

There are two possible candidates;

**(1) solar production of relativistic charged particles; or**

**(2) gamma rays produced by a nearby supernova. We now consider both possibilities.**

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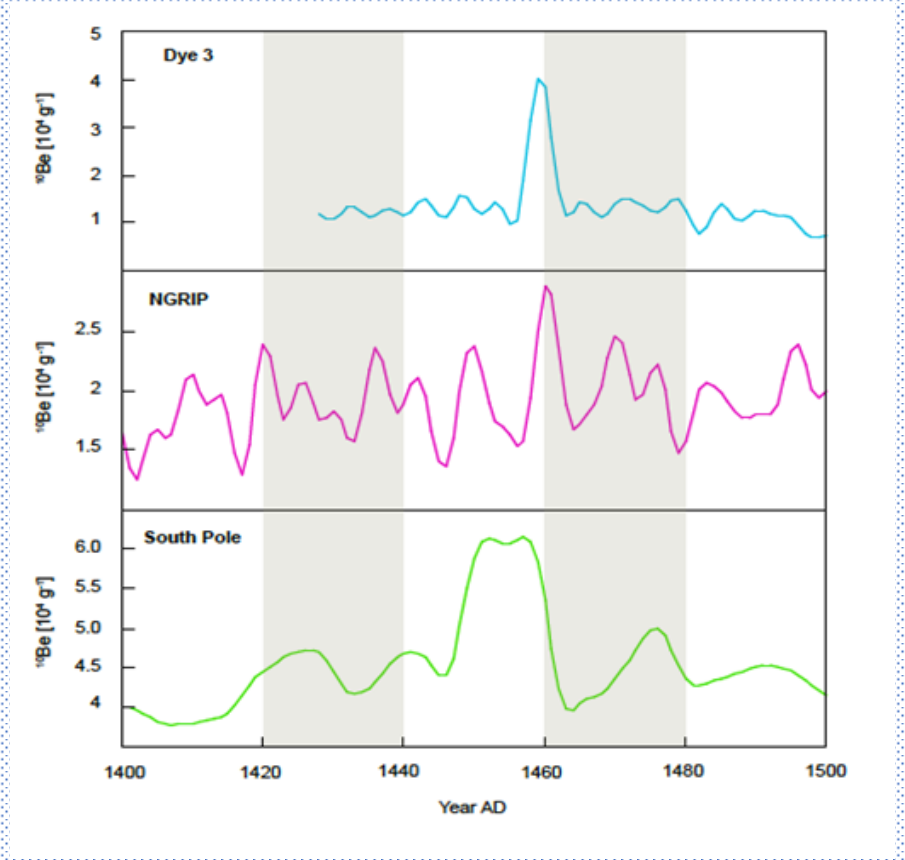


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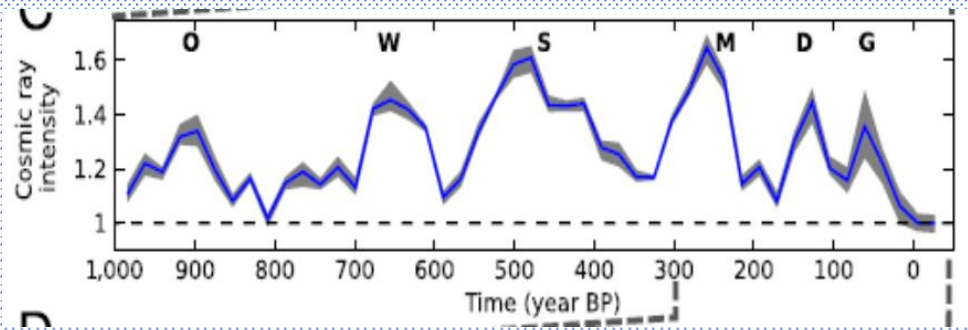


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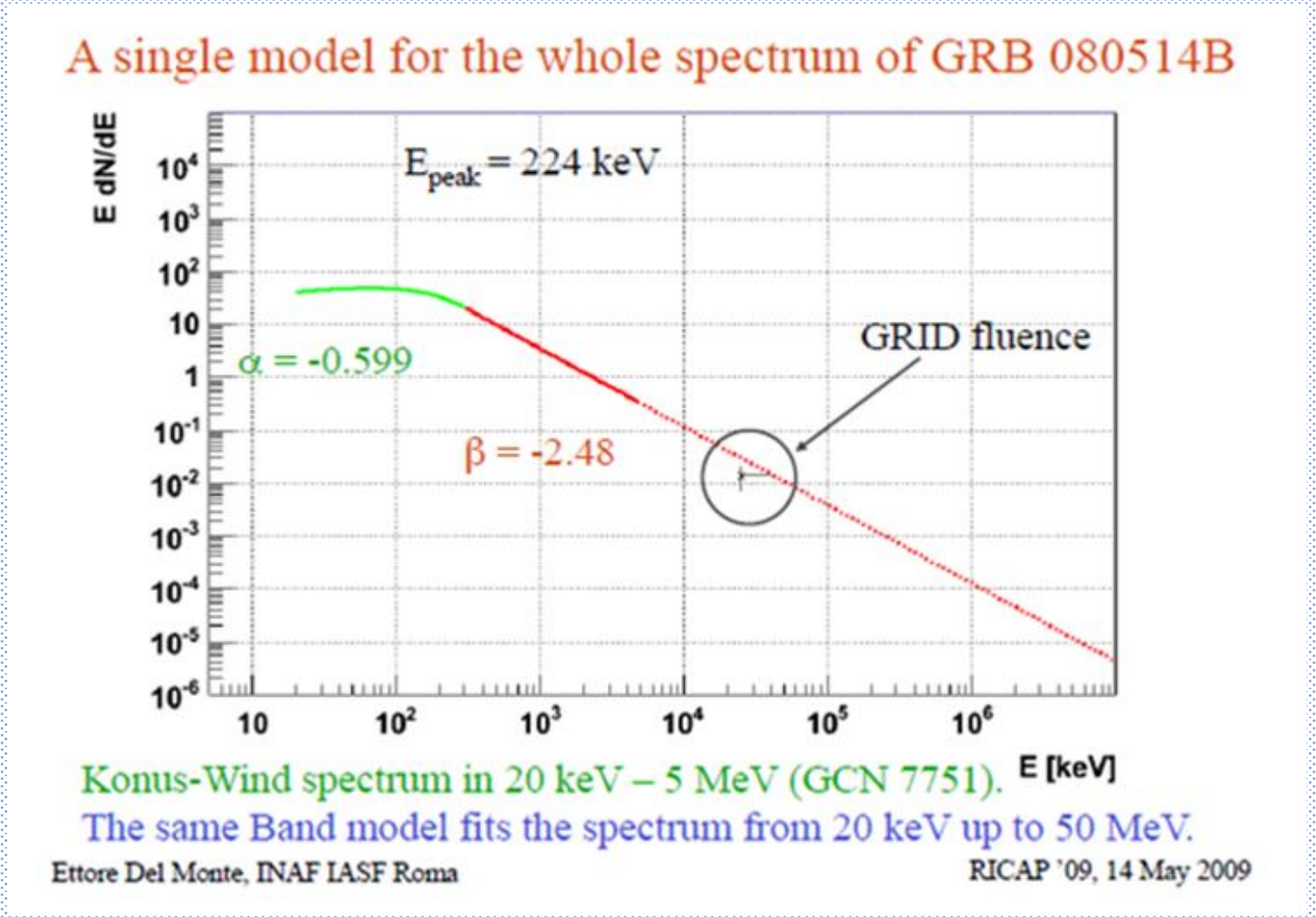
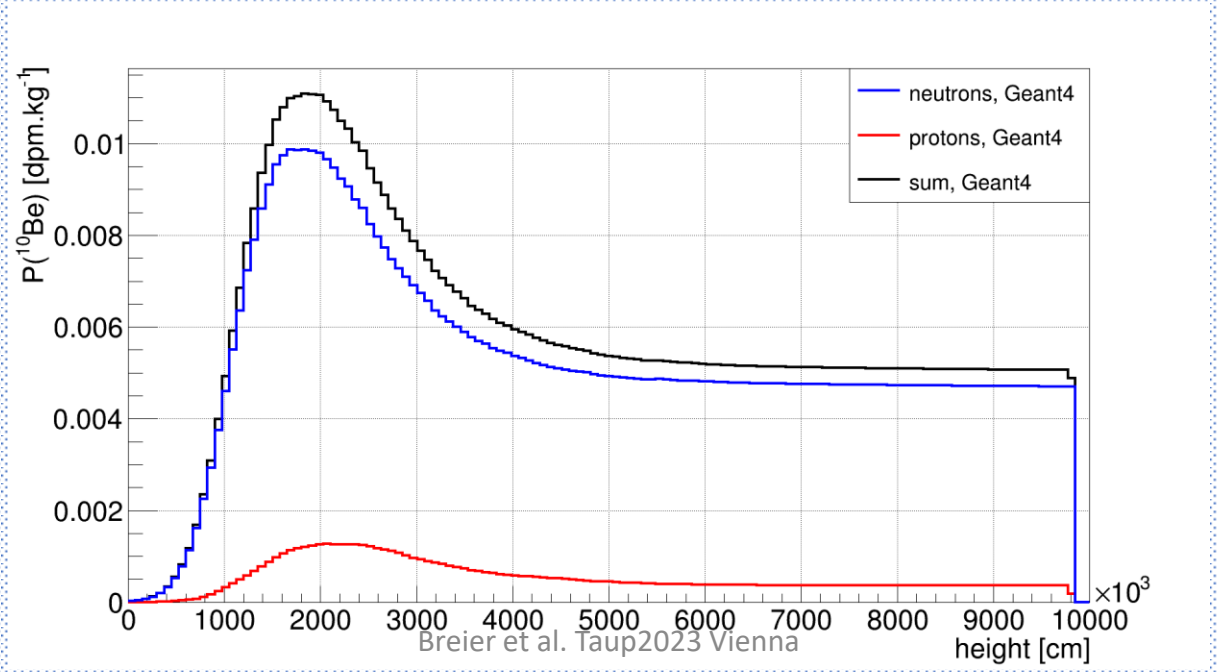
# Model spectrum for γ-rays from SN



# Results of γ-rays simulation

- As done previously for galactic cosmic rays (GCR), we have used the GEANT particle transport code to determine the $^{10}$Be yield of a unidirectional beam of high energy gamma rays, with a spectrum that peaks at 70 MeV.



# Results

- The production efficiency is much lower than for the GCR, however there is a partially compensating factor in that the geomagnetic field has no screening effect as in the case of the GCR. We find that a high energy gamma photon has a $^{10}$Be yield that is a factor of 100-130 times less than that of a relativistic cosmic ray.
- The cross-sections for $^{14}$C producing photo-spallation reactions are larger than those for $^{10}$Be. For the gamma spectrum used above, the GEANT4 code predicts a ~ 5-times greater yield for $^{14}$C yield compared to $^{10}$Be. The yield can be higher (~7-times) for a gamma spectrum with a strong lower energy bremsstrahlung component

# Conclusions

- The estimated gamma fluence of ~ 9 x $10^9$ photons/ $cm^2$ yields approximately the same quantity of $^{10}Be$ as is produced by the galactic cosmic rays in one year, consistent with the observed enhancements.
- The South- North asymmetry, the predicted one year pulse duration, and the predicted gamma ray fluence from a nearby (200pc) Type II SN are therefore all consistent with the hypothesis that the $^{10}Be$ enhancements in 1460 are a terrestrial record of the Vela Junior SN.
- Detailed modelling of the photo-spallation process will provide a better estimate of the gamma fluence at Earth from the $^{10}Be$ observations themselves.