SH.1.8 Ground level events
SH.3.6 Terrestrial effects: cutoffs, cosmic rays in atmosphere, cosmogenic nuclides

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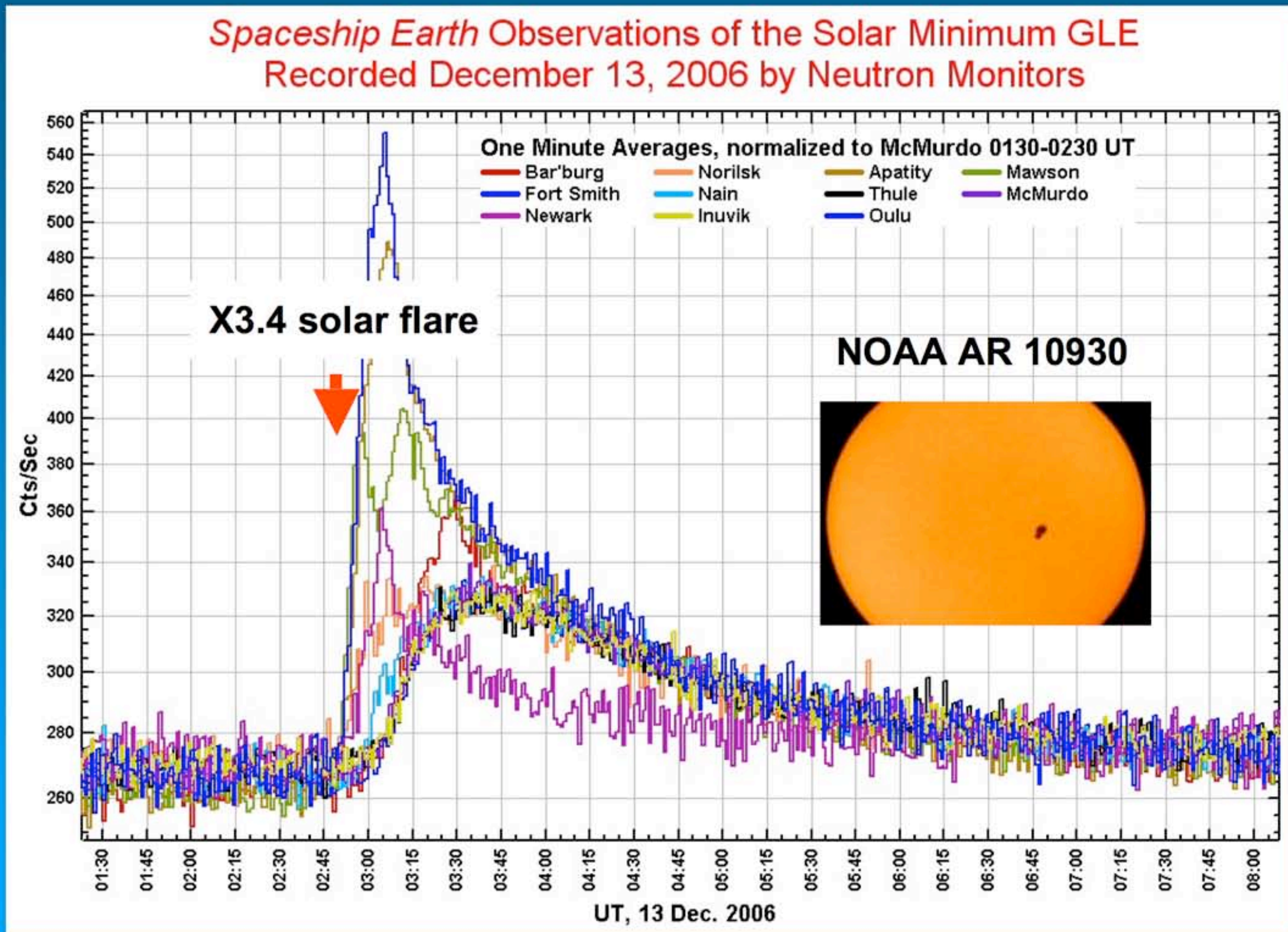
Number of Papers

	Total	Oral
SH1.8	28	13
SH3.6	42	15

Topics:

- The 13 December 2006 and the 20 January 2005 GLEs
- Geomagnetic Effects
- Effects in the Atmosphere
- Cosmogenic Nuclides, Nitrates, CR and the Sun
- New Techniques, „Potential Highflyers“
- Take home messages

New GLE: 13 December 2006

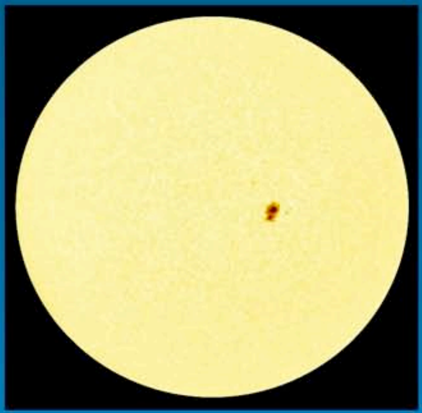


This GLE occurred near solar minimum, but it was a large event, exceeding 100% increase at Oulu

adapted from Paper 376, Bieber et al.

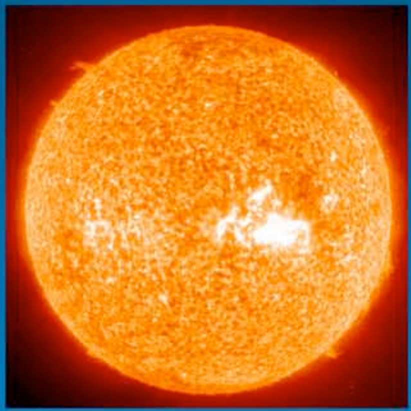
The Sun on 13 December 2006

White light

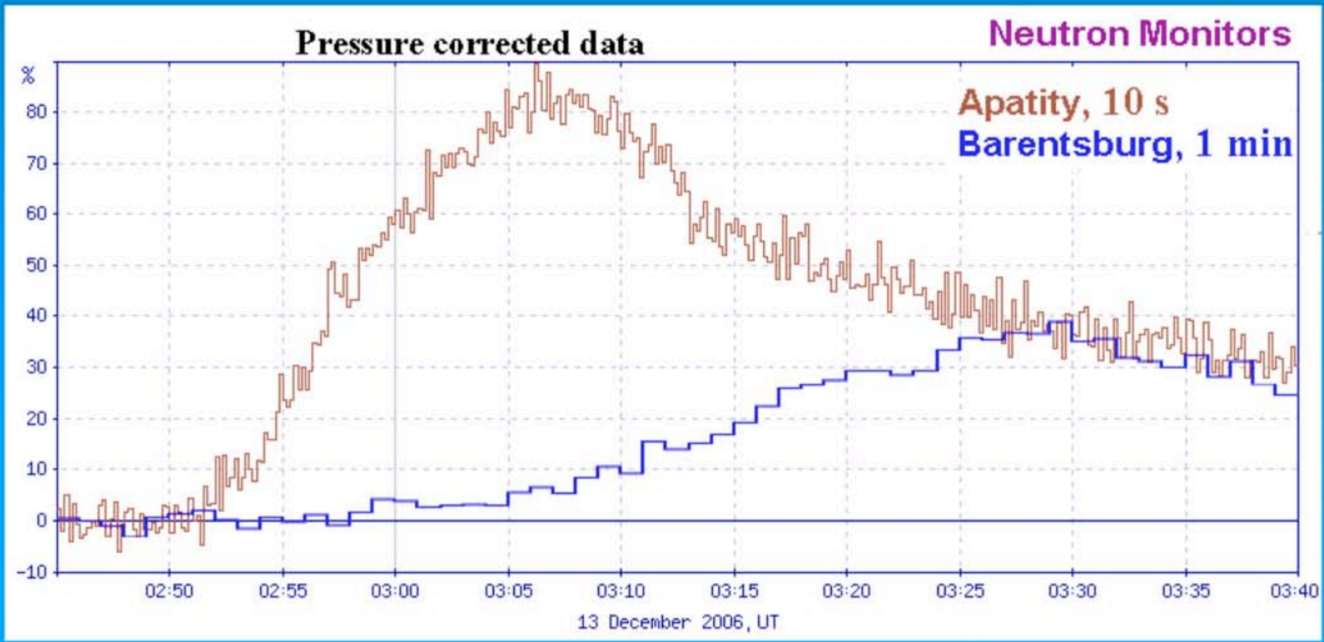


Active region AR10930

30 nm emission

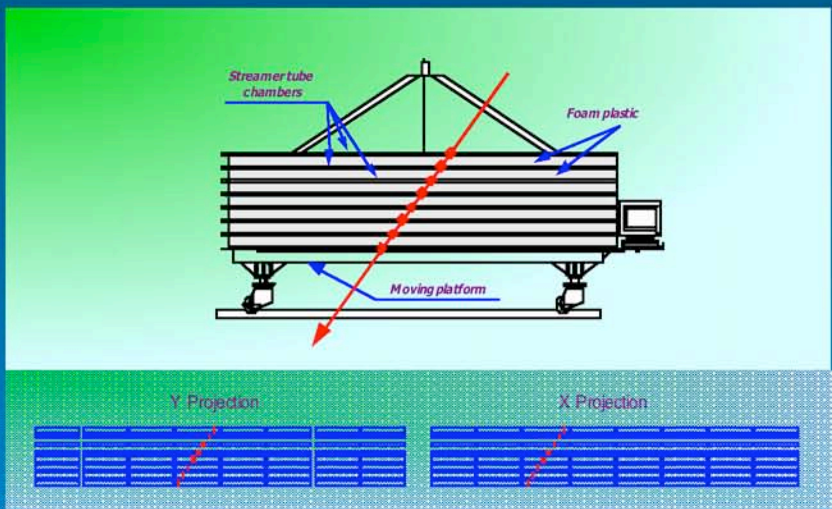


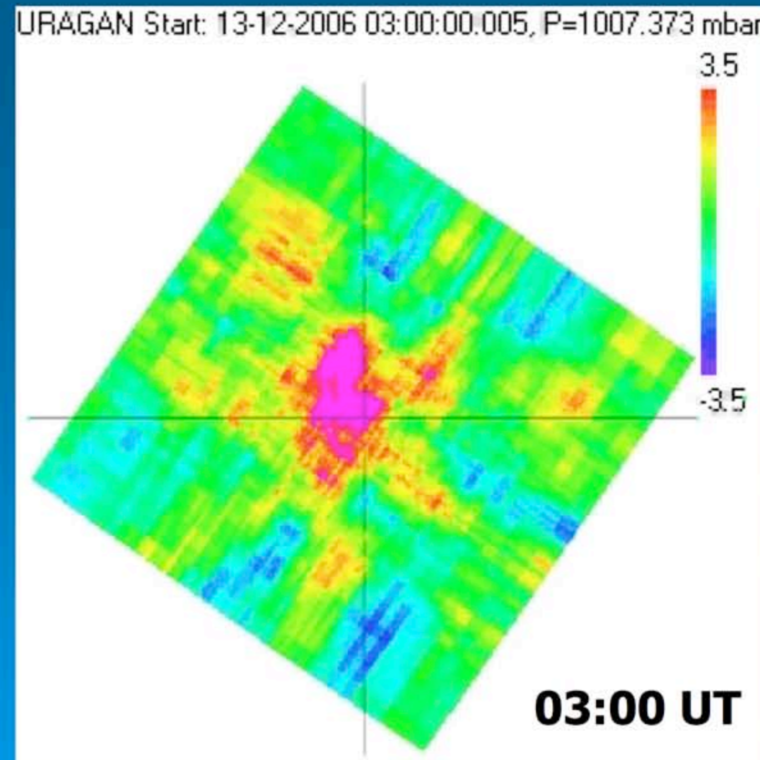
Ground level effect of a solar flare X3.4/2B S06 W24 02.26 UT



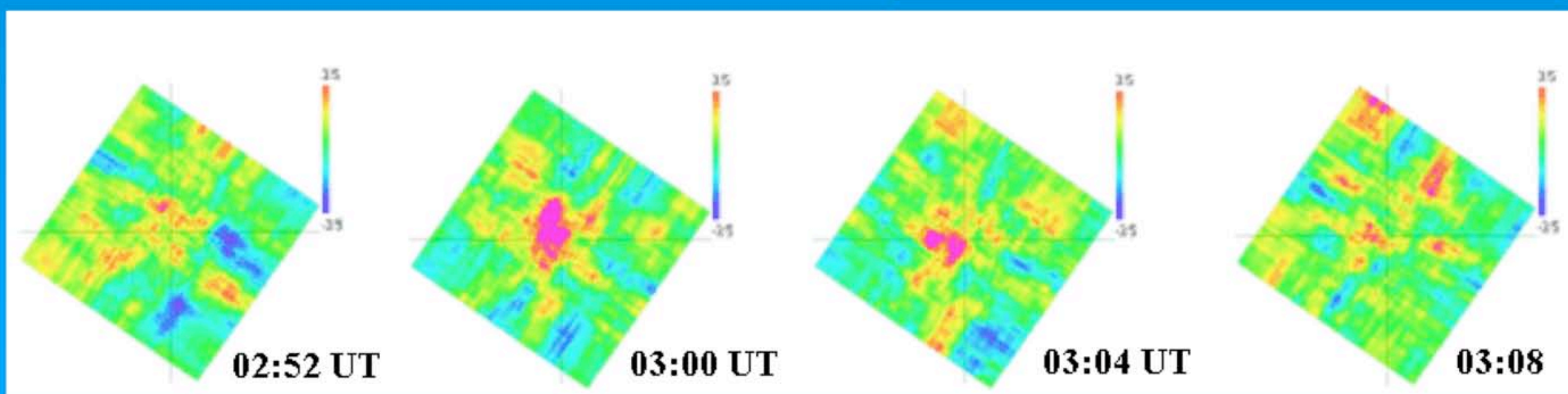
Paper 643, Vashenyuk et al.

13 December 2006 GLE - URAGAN muon hodoscope





Moscow 37°40'E, 55°39'N
zenith angles from 0 to 80°
angular resolution ~ 0.7°,
total area ~ 46 (23) m²



Paper 298, Timashkov et al.

The 13 December 2006 GLE

"A Maverick GLE" (376 Bieber et al.)

15 Papers

168	Stoker	357	Heber et al.
298	Timashkov et al.	412	Grigoryev et al.
362	Vashenyuk et al.	643	Vashenyuk et al.
376	Bieber et al.	658	Vashenyuk et al.
680	Balabin et al.	1002	Storini et al.
715	Shea & Smart	1073	Eroshenko et al.
897	McCracken & Moraal	1173	Tang
172	Kudela & Langer	1182	Flückiger et al.

GLE Standard Analysis Method

(McCracken, Shea, Smart, Dorman, …)

$$\Delta N(t) = \sum_{R_c}^{20GV} \psi_p(R,t) \cdot F(\theta(R),t) \cdot S_p(R) \cdot \Delta R$$

where

R, R_c = rigidity, eff. vertical cutoff rigidity

t = time

$\psi_p(R,t)$ = solar proton flux

θ = pitch angle

$F(\theta(R),t)$ = pitch angle distribution

$S_p(R)$ = yield function

Data from worldwide network (>20 Stations)

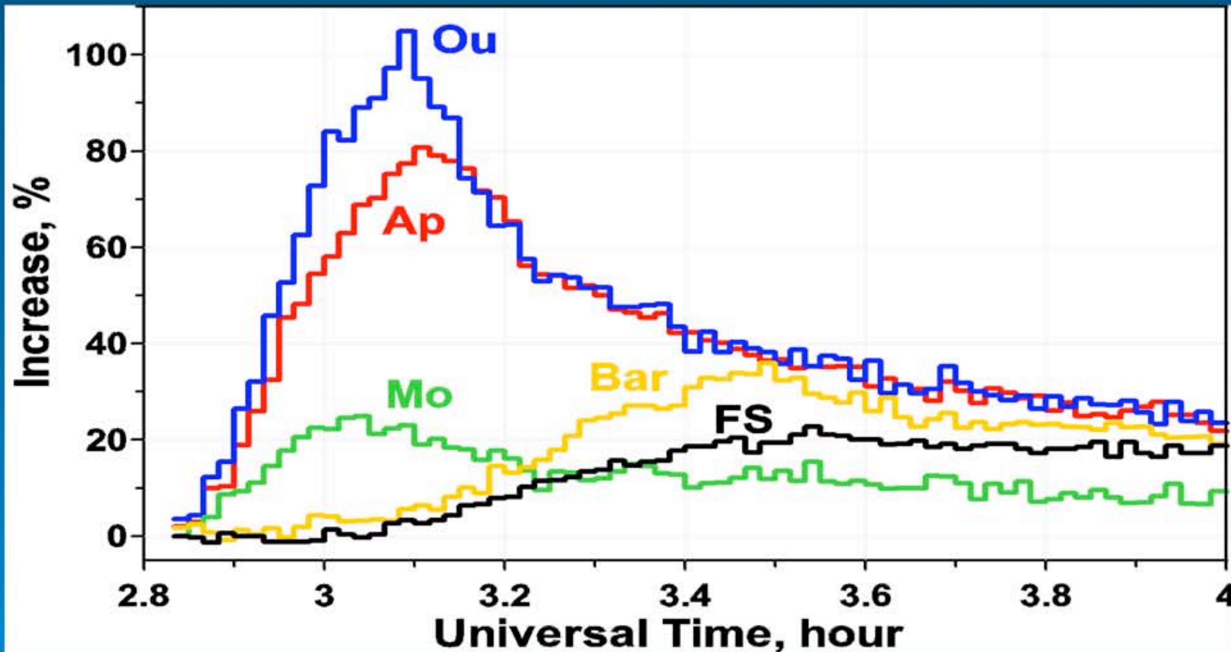
Assumptions necessary for:

- pitch angle distribution $F(\theta)$
- spectrum $\psi_p(R,t)$

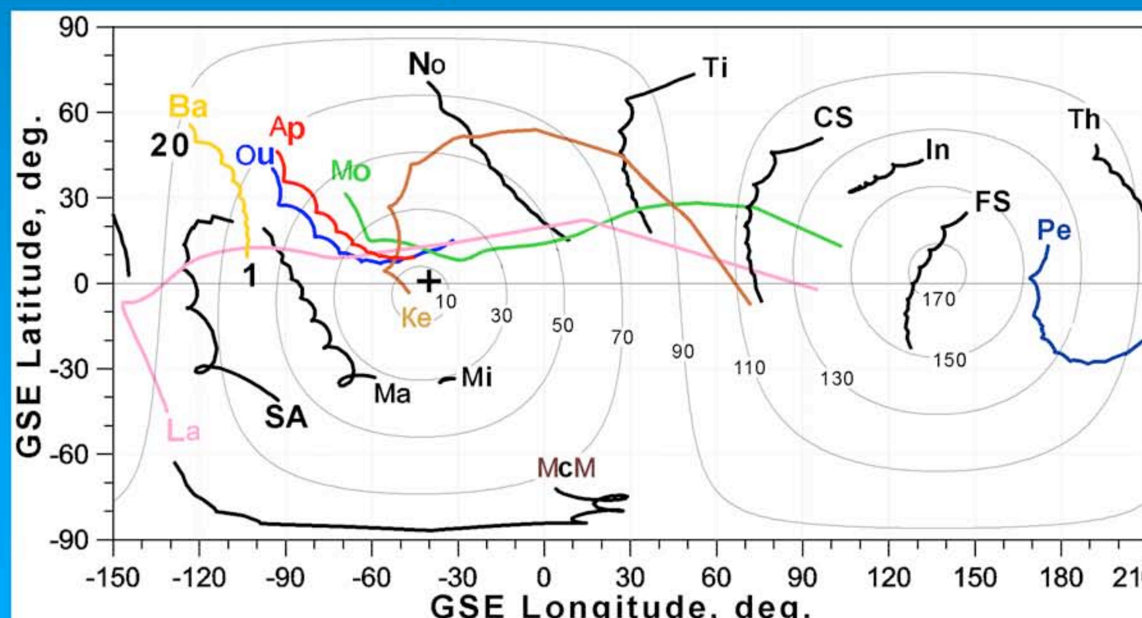
By adjusting the input parameters one calculates what the detectors should measure → iterative process

Detailed information required about detector yield and particle propagation in the Earth's magnetic field

The 13 December 2006 GLE



Increase profiles at neutron monitors



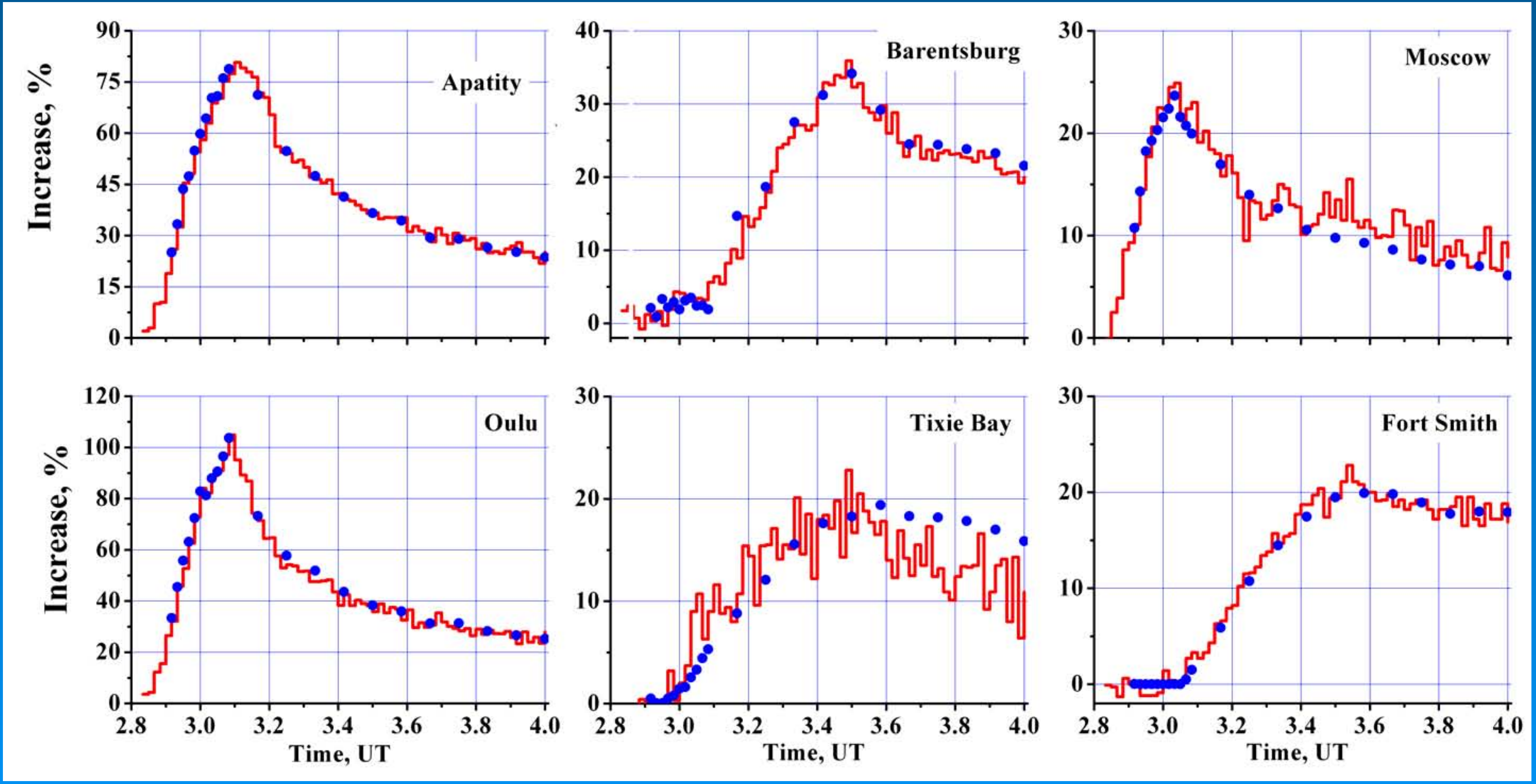
Map of neutron monitors' asymptotic cones. Cross is IMF direction from ACE data

Paper 643, Vashenyuk et al.

The 13 December 2006 GLE

– – – increase profiles at neutron monitors

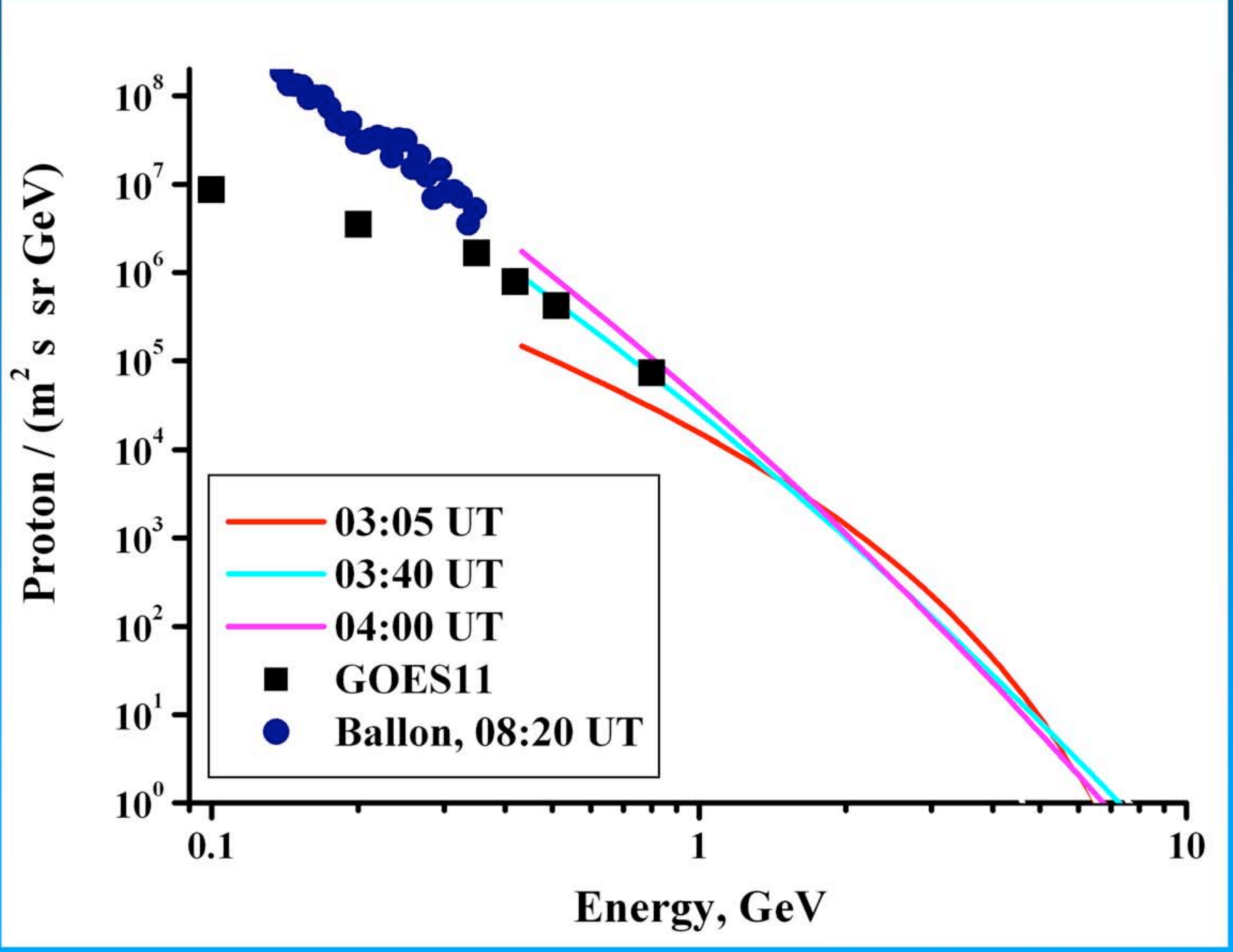
●●● modeling results



Paper 643, Vashenyuk et al.

The 13 December 2006 GLE

Spectrum

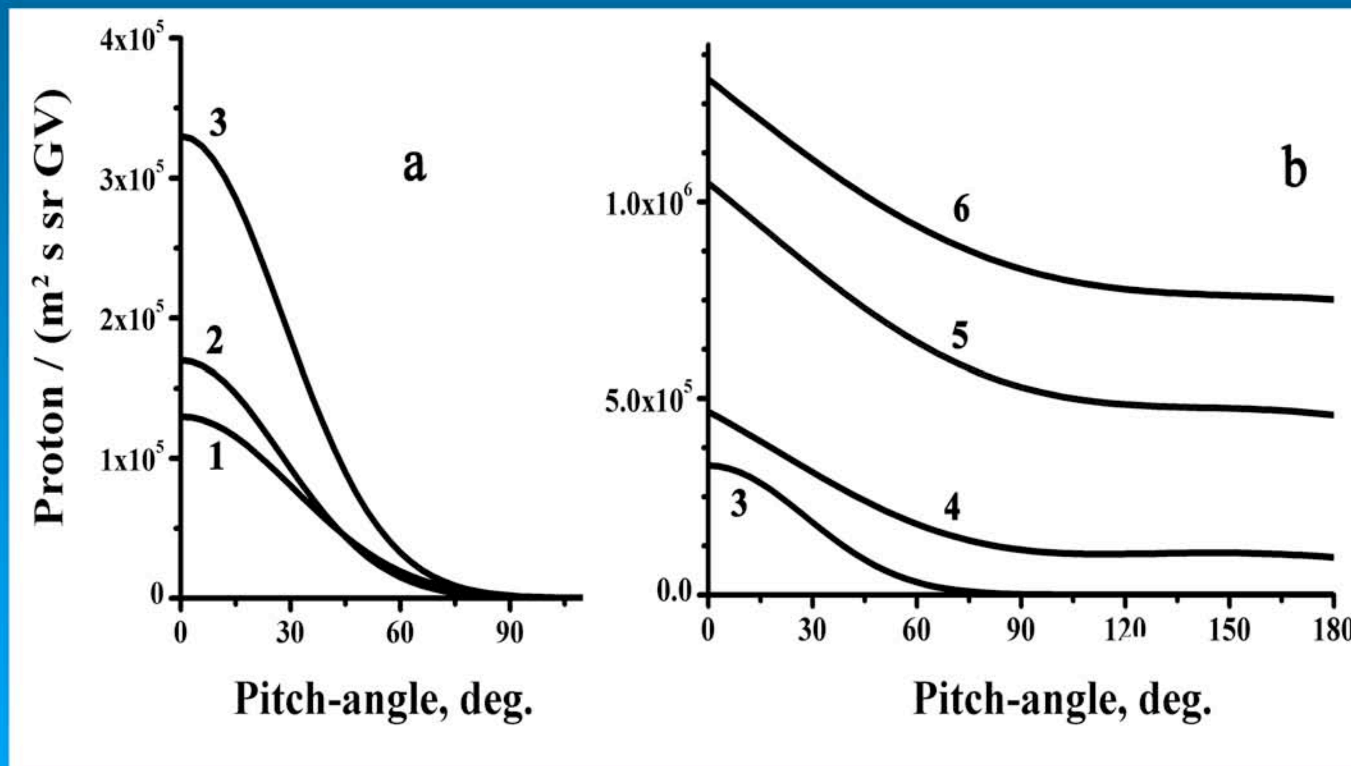


Paper 643, Vashenyuk et al.

The 13 December 2006 GLE
Pitch Angle Distribution

Dynamics of derived pitch angle distributions of RSP during the 13.12.2006 GLE

From 02:57 to 3:05 (profiles 1-3) a collimated beam of particles existed with a character width of~30°



Paper 643, Vashenyuk et al.

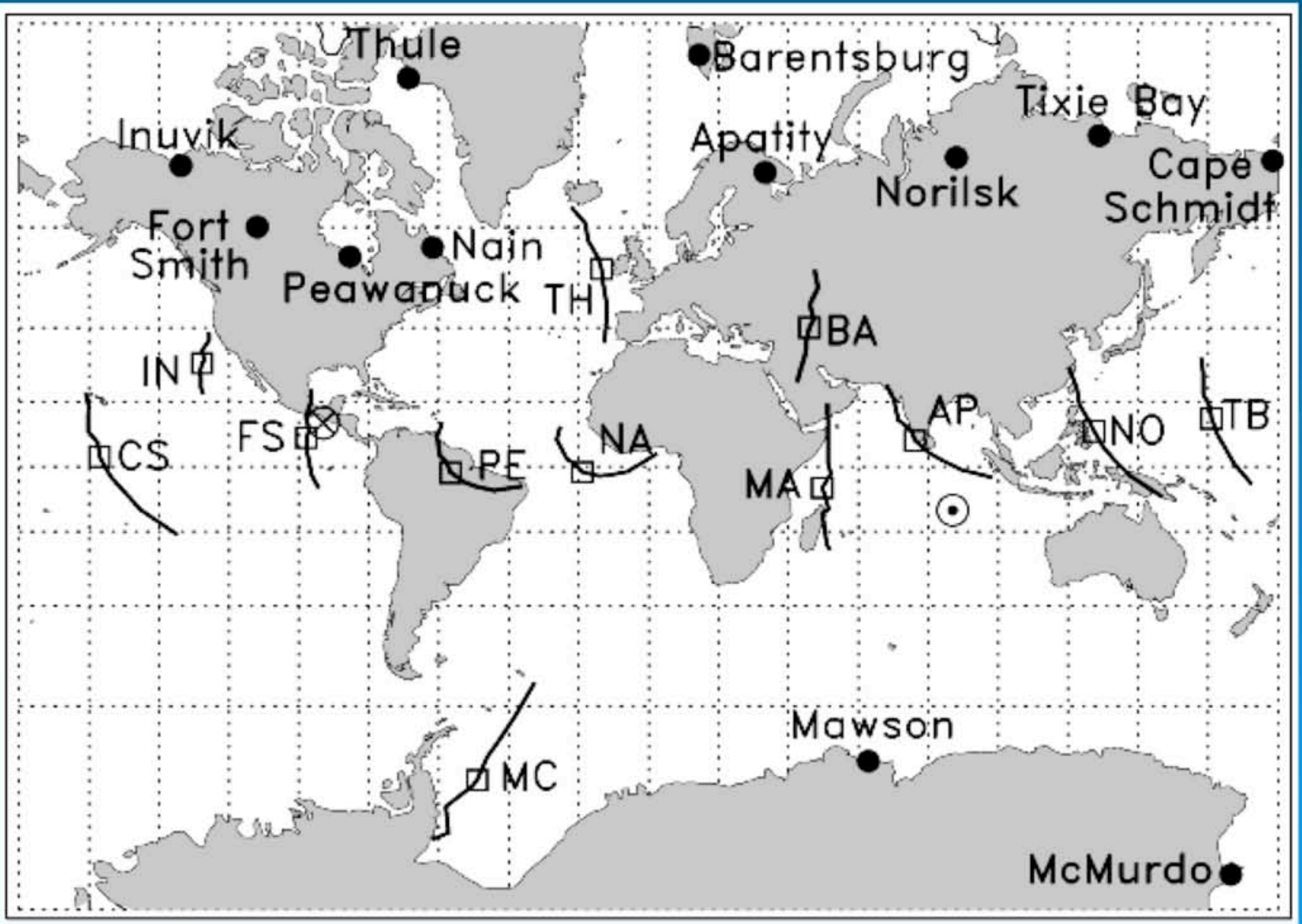
The 13 December 2006 GLE

Alternative Advanced Analysis

Paper 376, Bieber et al.

Spaceship Earth

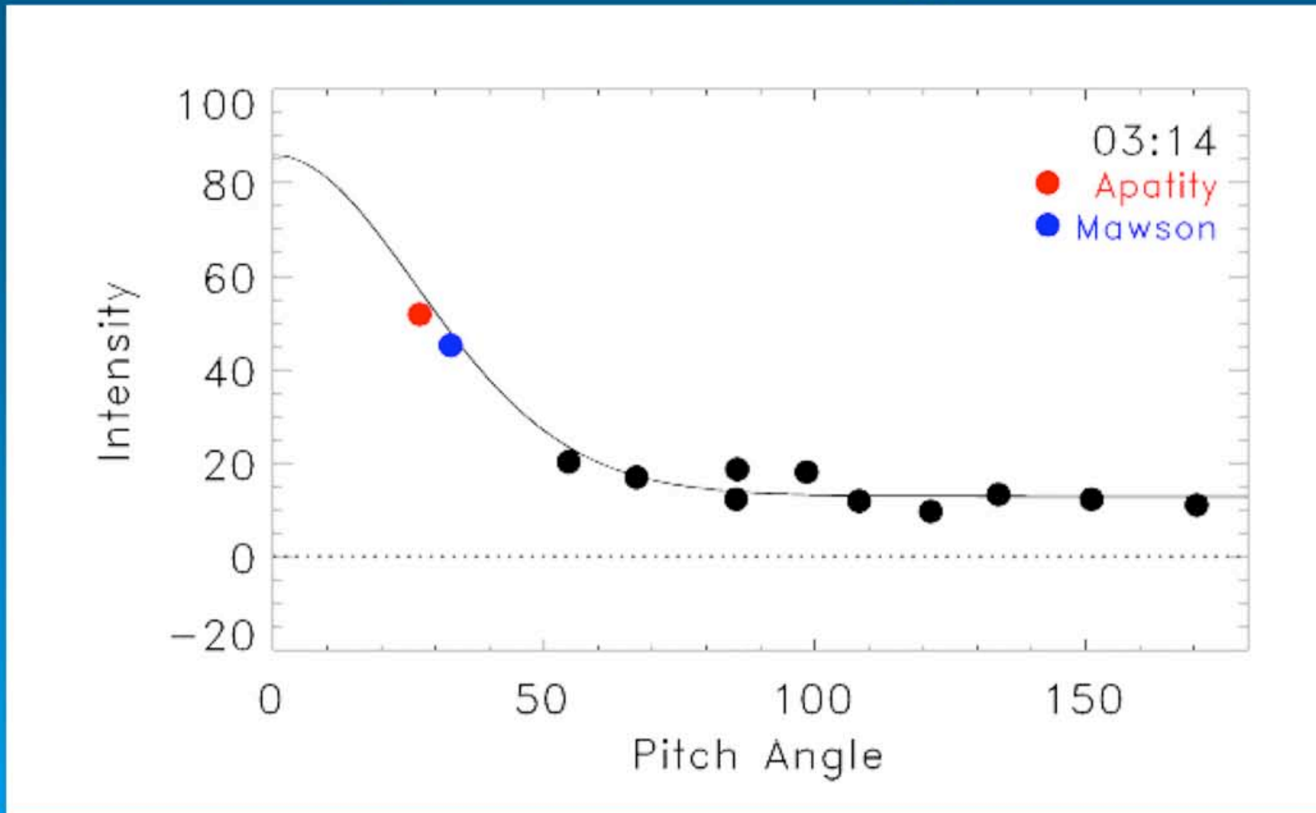
Asymptotic Viewing Directions at Start of Event



- Circles show station geographical locations
- Open squares show asymptotic direction for a median rigidity solar particle
- Lines show range (10- to 90-percentile rigidity) of viewing directions for each station
- Circled dot and circled X denote nominal Sunward and anti-Sunward Parker directions, respectively

Paper 376, Bieber et al.

Spaceship Earth Event Modeling: Step 1



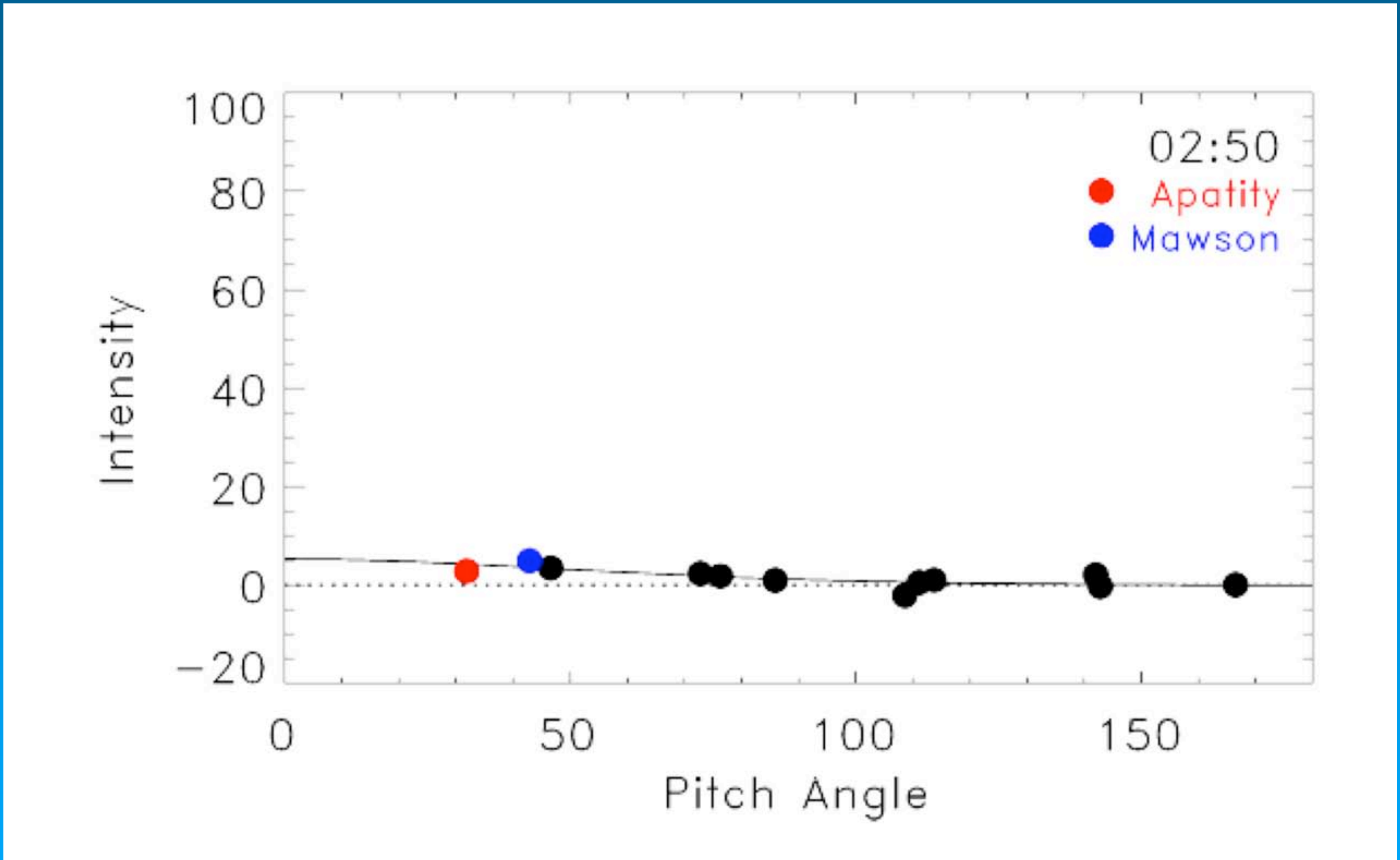
- Step 1: Individual station data were fitted to an angular distribution of the form

$$f(\mu) = c_0 + c_1 \exp(b\,\mu),$$

with μ cosine of pitch angle, and c_0, c_1, and b free parameters. The symmetry axis from which pitch angles are measured was also a free parameter.

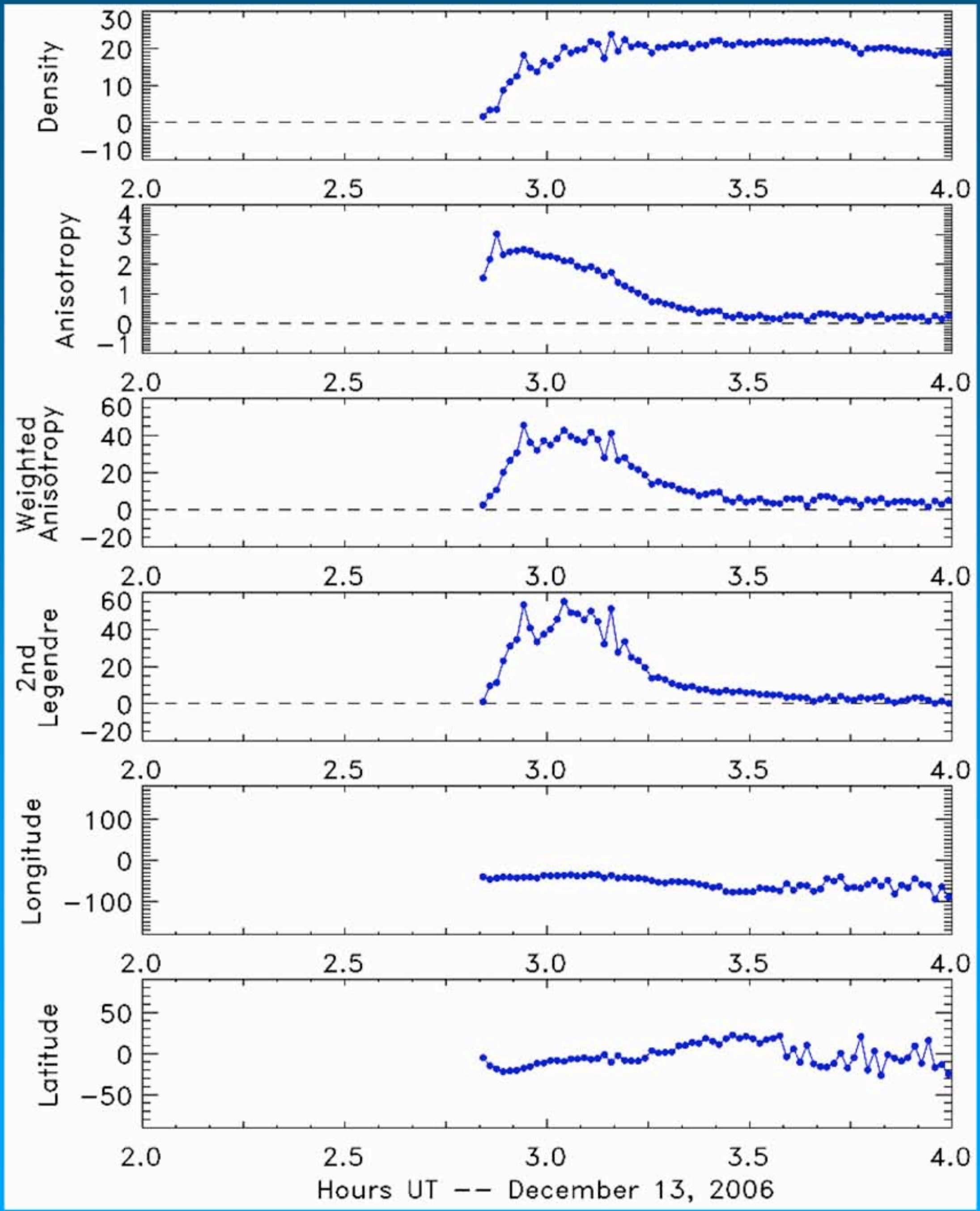
Paper 376, Bieber et al.

Spaceship Earth Event Modeling: Step 1



Paper 376, Bieber et al.

Spaceship Earth Event Modeling: Step 2



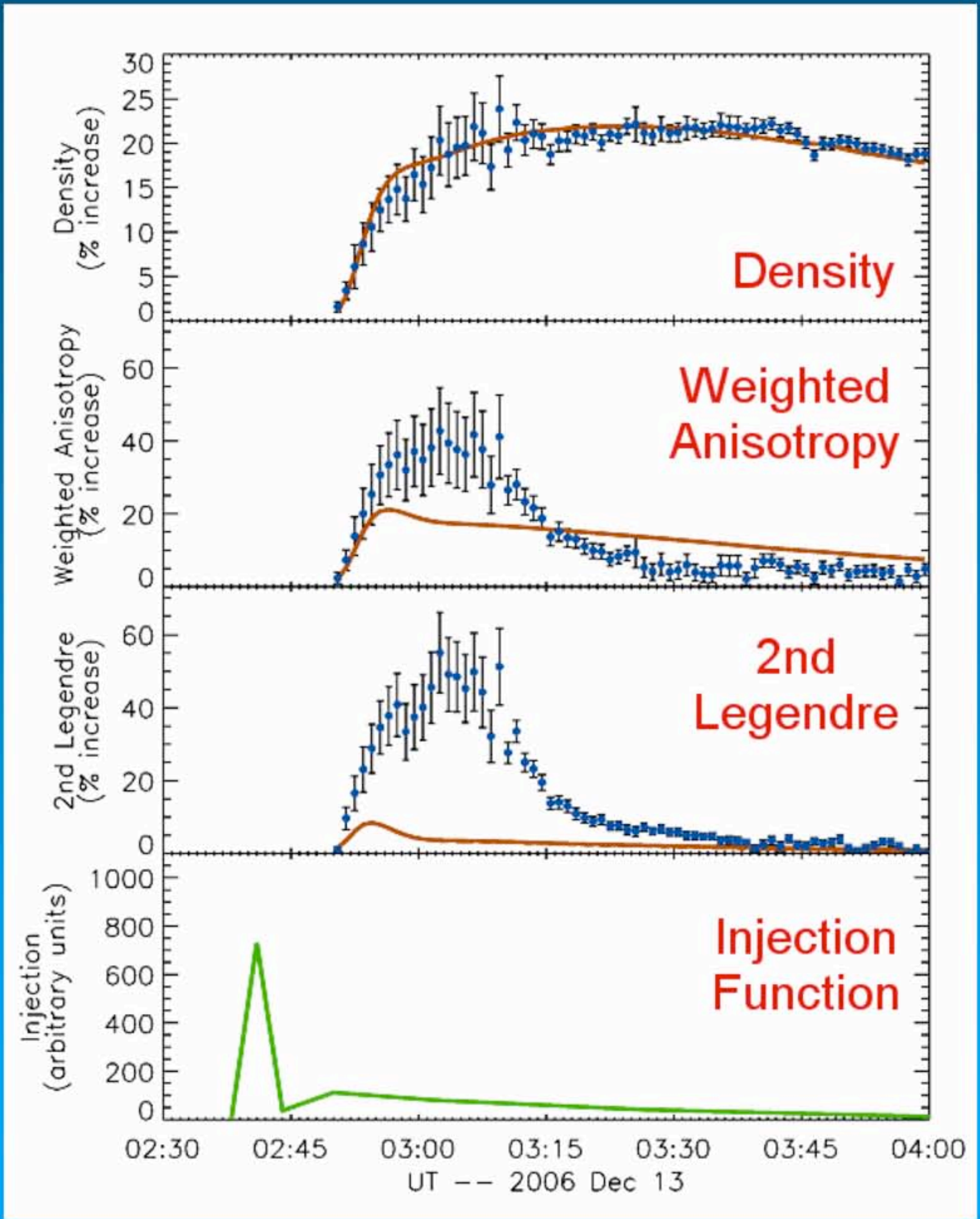
- Step 2:
  The first 3 Legendre coefficients, f_0, f_1, f_2, of the derived distribution were computed from f(μ).

  They are shown at left as
  - "Density",
  - "Weighted Anisotropy", and
  - "2nd Legendre."

  Longitude and latitude of the derived symmetry axis are also shown, as is the ordinary anisotropy, f_1/f_0.

Paper 376, Bieber et al.

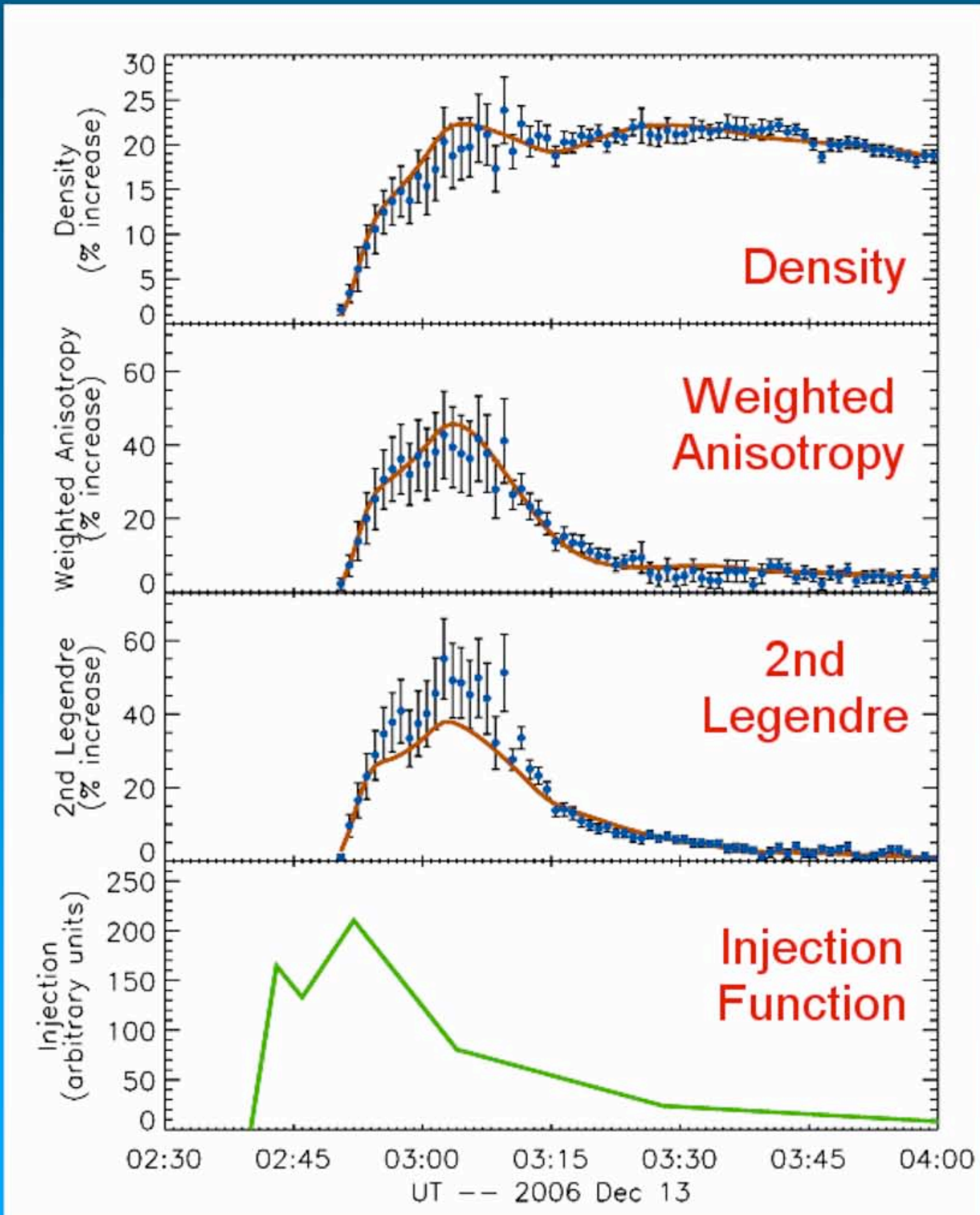
Event Modeling: Standard Parker Field



- Step 3: The Legendre coefficients as functions of time are fitted to numerical solutions of the Boltzmann equation. Free parameters are the scattering mean free path and profile of particle injection at the Sun, represented by a piecewise-linear function.
- A standard Parker IMF does not yield a satisfactory fit: The optimal mean free path of 0.23 AU provides a good fit to density, but not to weighted anisotropy or 2nd Legendre.
- Based on our experience modeling the Bastille event, we suspect a downstream magnetic mirror may be affecting transport in this event.

Paper 376, Bieber et al.

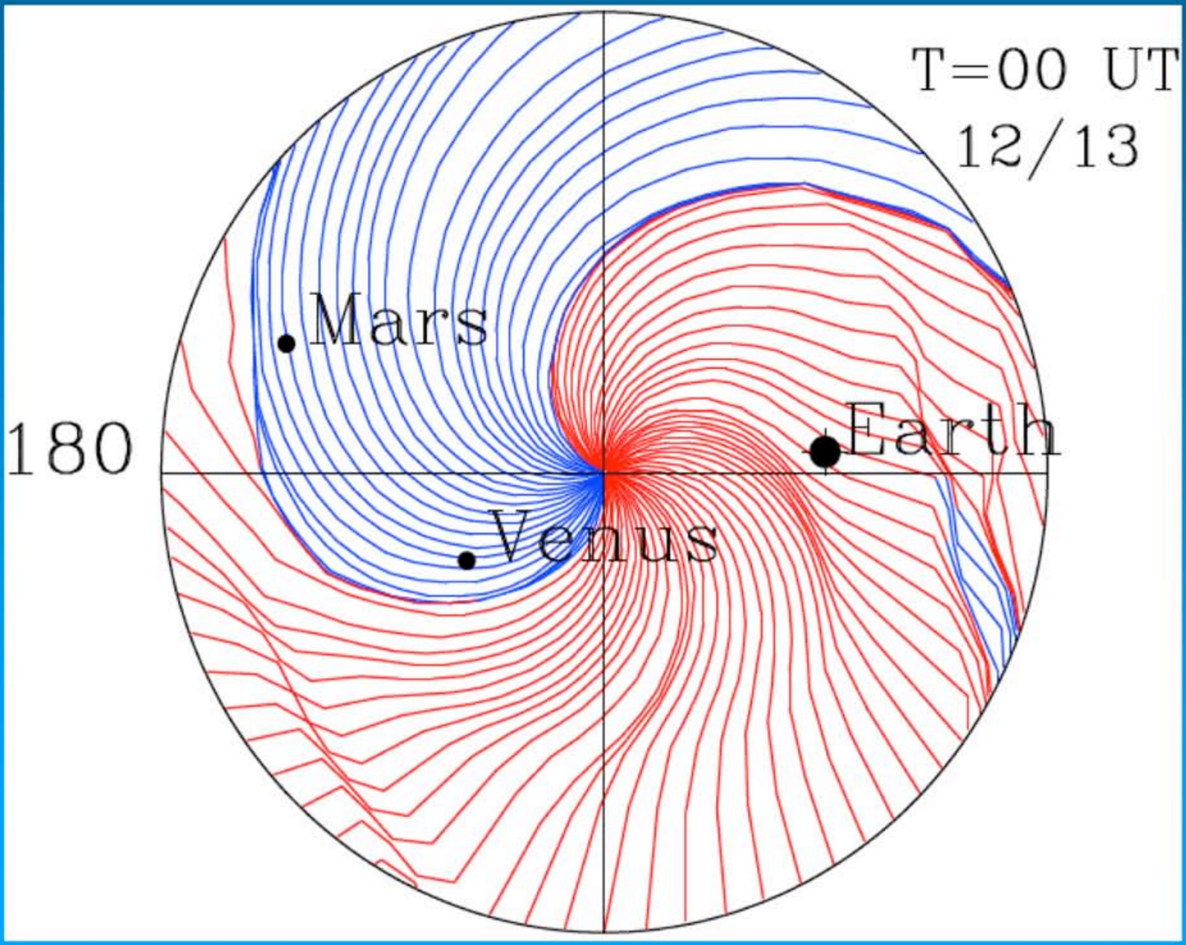
Event Modeling: Downstream Magnetic Bottleneck (Preliminary)



- A bottleneck fit works much better. Here, the optimal mean free path is much larger, 1.08 AU, and the optimal bottleneck location is at 1.52 AU.

Paper 376, Bieber et al.

A Downstream Magnetic Mirror is supported by a "Fearless Forecast" of the IMF Configuration



- A "Fearless Forecast" (left) suggests Earth was connected to a downstream compression region at ~1.6 AU at event onset
- This is reminiscent of the Bastille event, in which transport was affected by a downstream magnetic bottleneck (Bieber et al., *J. Geophys. Res.*, **567**, 622-634, 2002)

Fearless forecast from
http://gse.gi.alaska.edu/recent/archive/20061212/ec8_recent.pdf

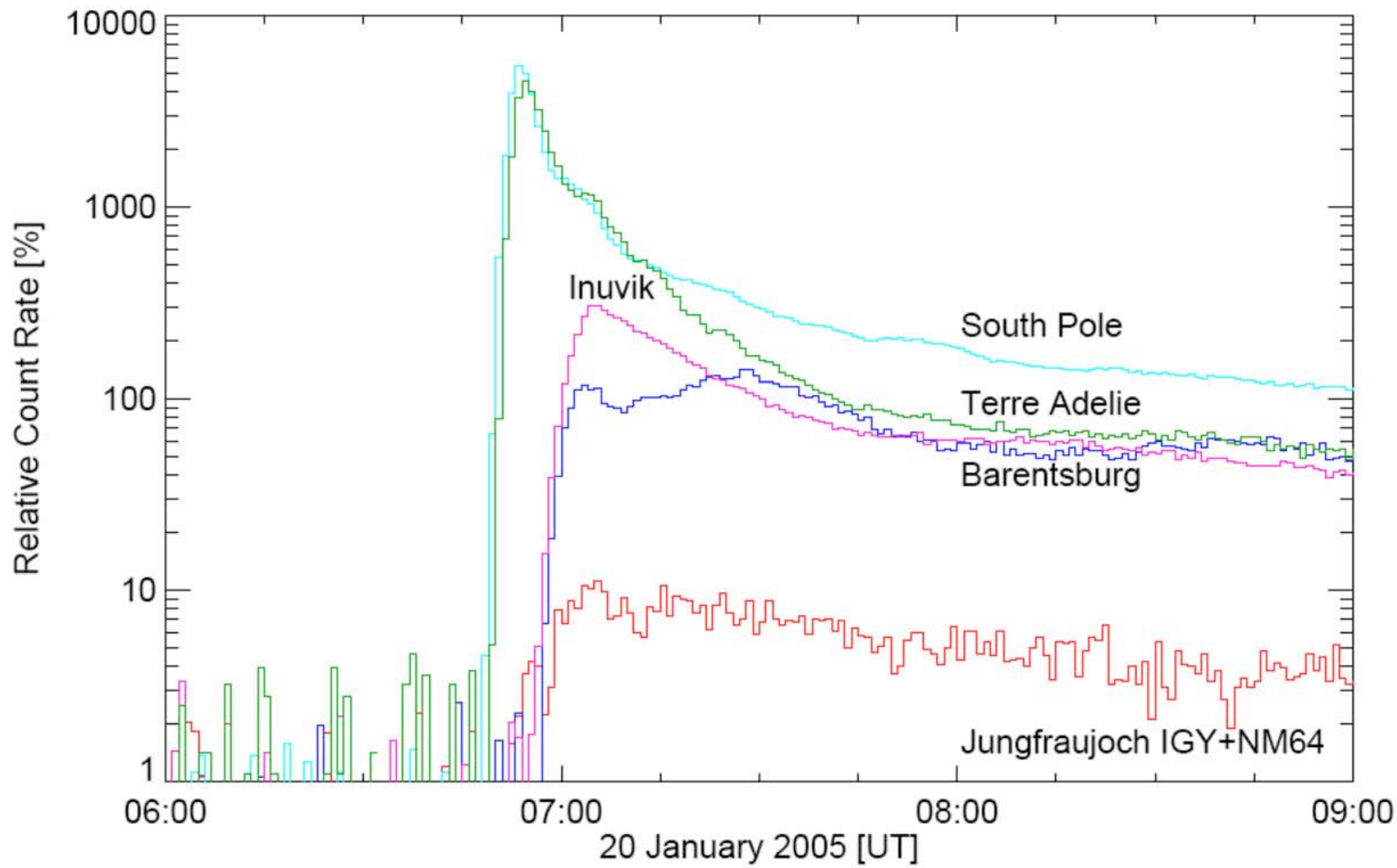
Paper 376, Bieber et al.

The 20 January 2005 GLE
Progress since 29th ICRC

10 Papers

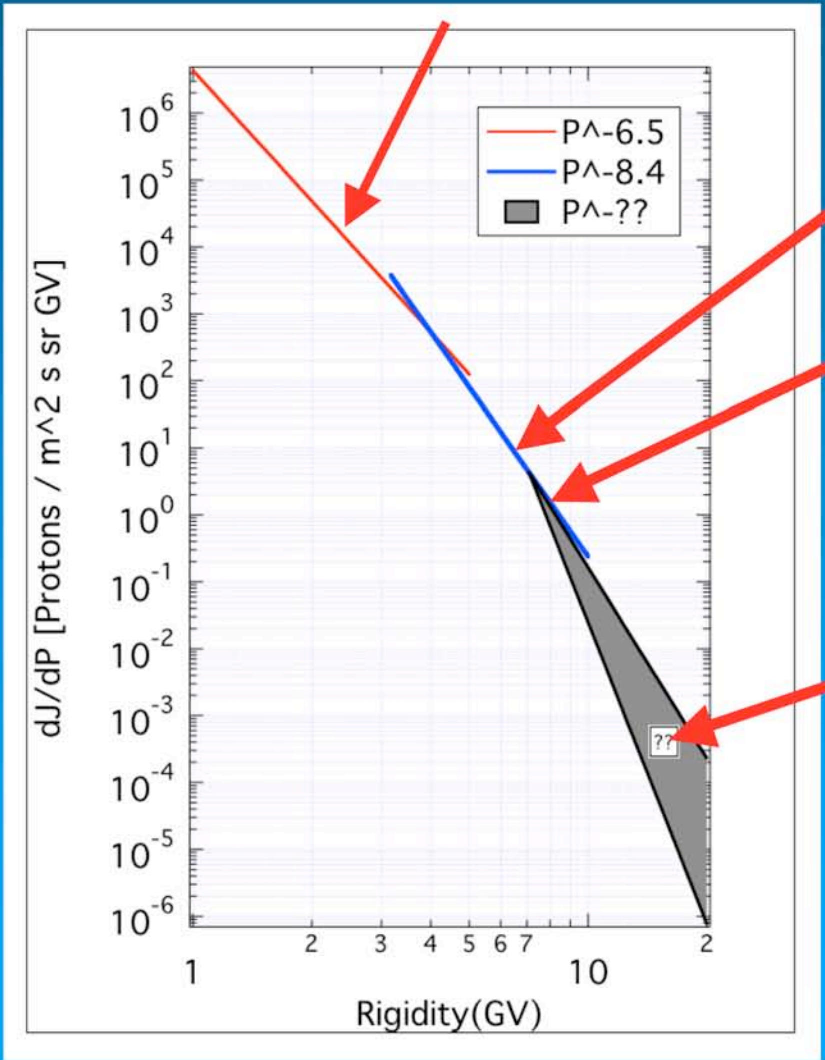
33	Dvornikov et al.	862	Moraal et al.
172	Kudela & Langer	897	McCracken & Moraal
643	Vashenyuk et al.	1152	Morgan et al.
658	Vashenyuk et al.	1009	Storini & Damiani
715	Shea & Smart	1182	Flückiger et al.

The 20 January 2005 GLE



The 20 January 2005 GLE
Spectrum

Durham/Mt. Washington



Milagro/Climax

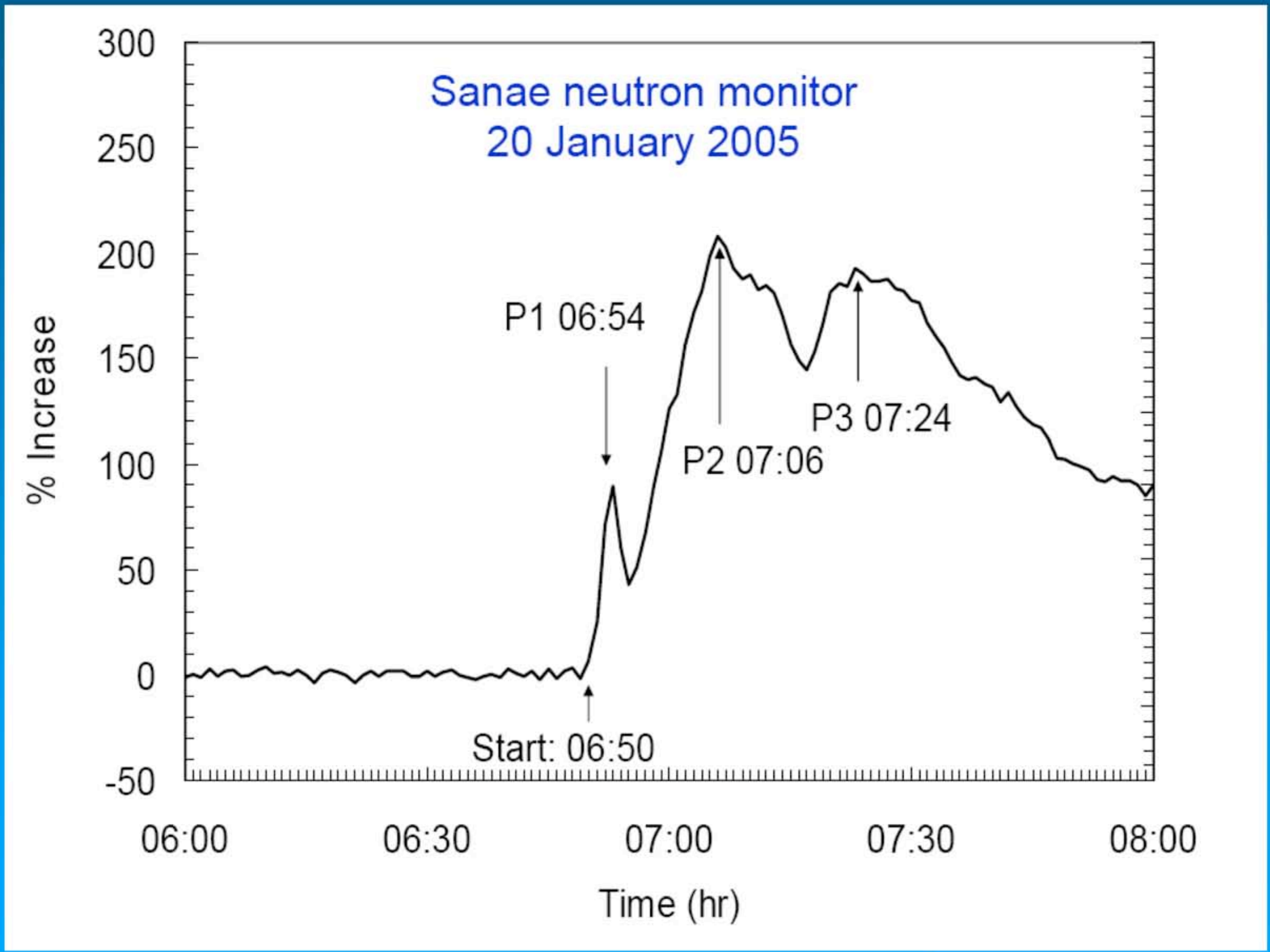
Milagro/Milagro

Higher, unanalyzed Milagro channels

Spectral index softens from 6.5 to ~8 at ~4GV

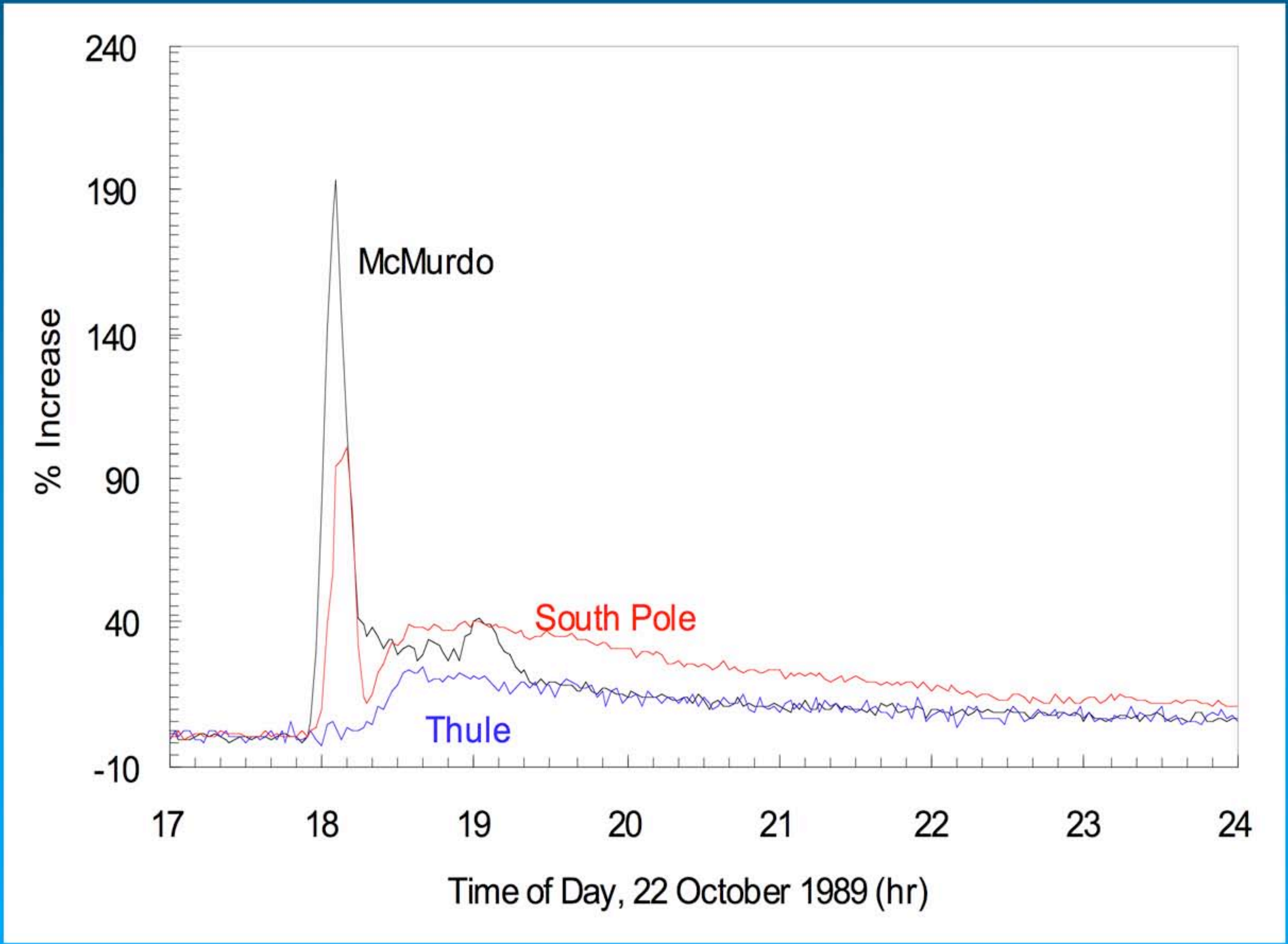
Paper 1152, Morgan et al.

The 20 January 2005 GLE
Two Acceleration Mechanisms?



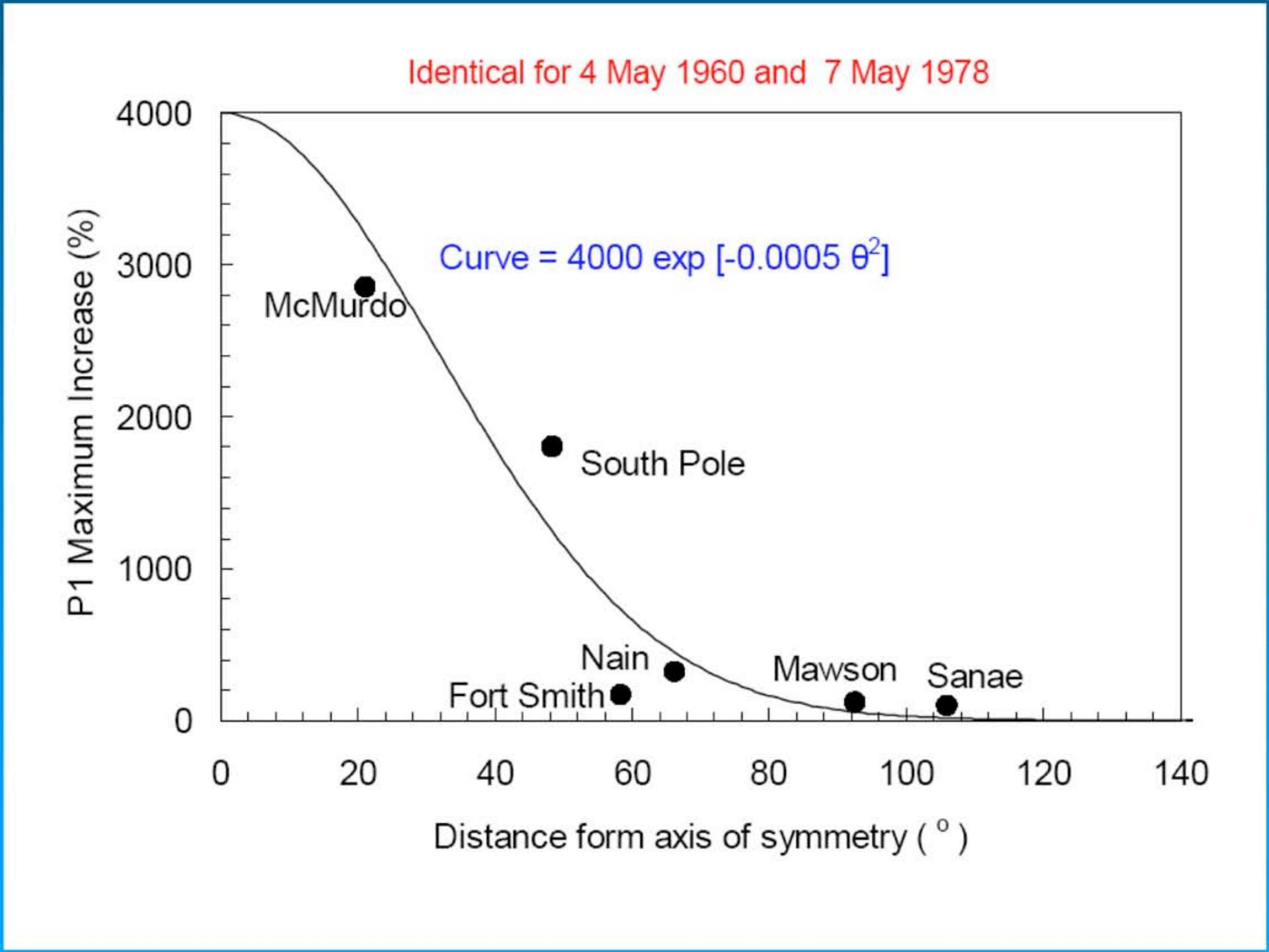
Paper 862, Moraal et al.

P1- A Common Occurrence
(After Shea and Smart, 1996)



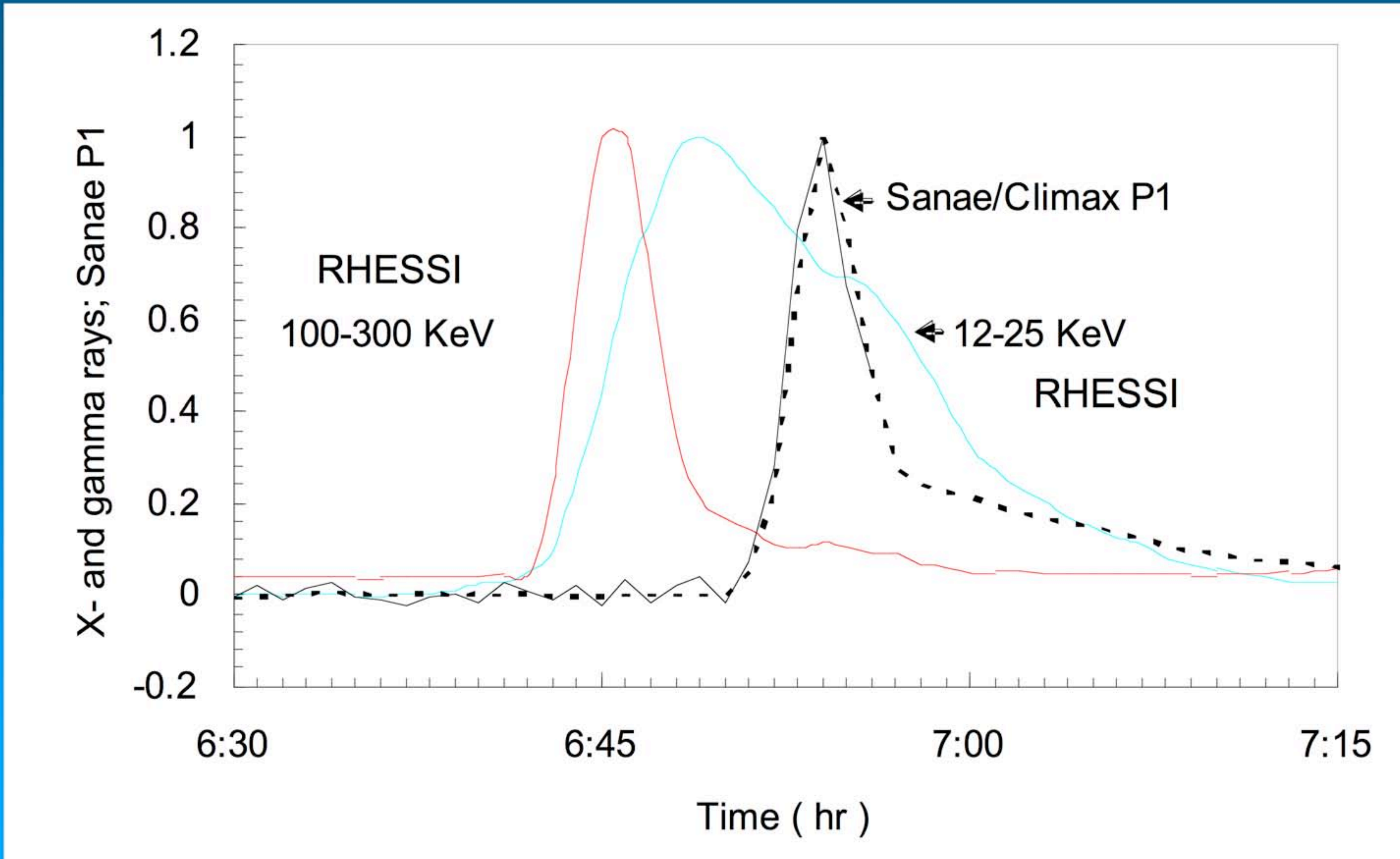
Paper 897, McCracken & Moraal

The 20 January 2005 GLE
Pitch Angle Distribution



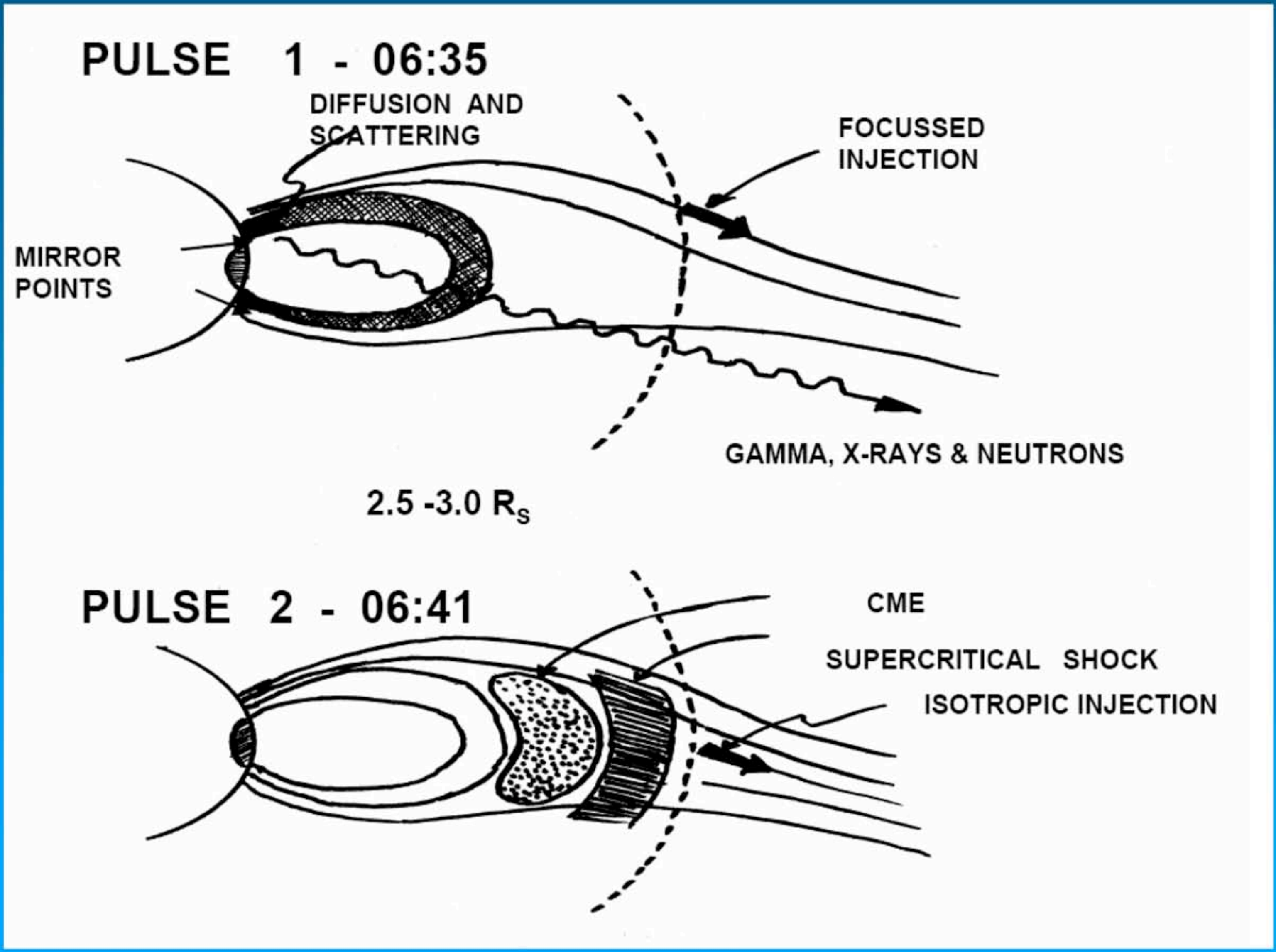
Paper 862, Moraal et al.

The 20 January 2005 GLE
Two Acceleration Mechanisms?



Paper 862, Moraal et al.

The 20 January 2005 GLE
Two Acceleration Mechanisms?



Paper 897, McCracken & Moraal

THE GENERIC SOLAR ENERGETIC PARTICLE EVENT (GLE and Lower Energies)

THE IMPULSIVE PHASE

A highly anisotropic pulse of cosmic rays at Earth
Coincident release of high energy gamma and neutron pulses
Hard cosmic ray spectrum
Acceleration low in corona
Scatter free propagation due to focusing close to the Sun.
High He/He ratio; high ionisation state.
From western third of solar disk

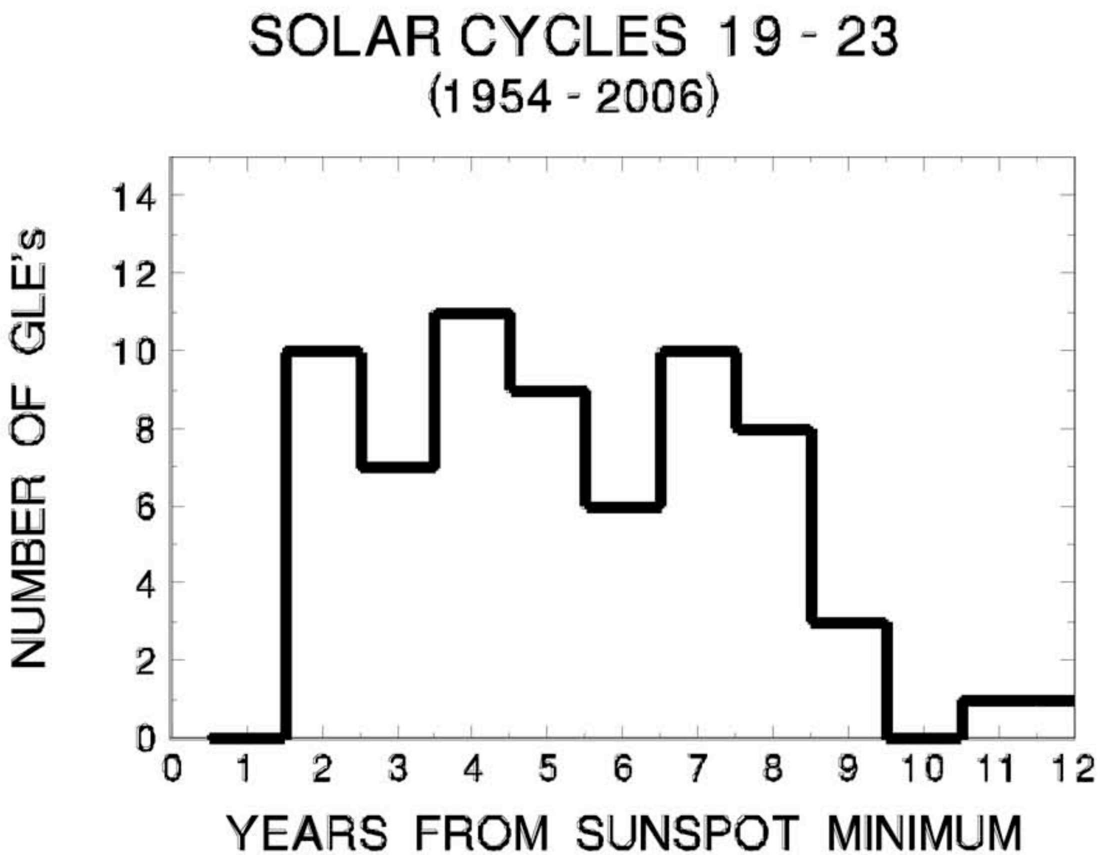
THE GRADUAL PHASE

Mildly anisotropic pulse of cosmic radiation at Earth
Soft cosmic ray spectrum
Acceleration high in the corona, >2.5-3.0 R_s
Diffusive propagation to Earth
From central regions of solar disk

Similar conclusion by Vashenyuk et al., Paper 643

Paper 897, McCracken & Moraal

GLEs during Solar Cycles 19-23



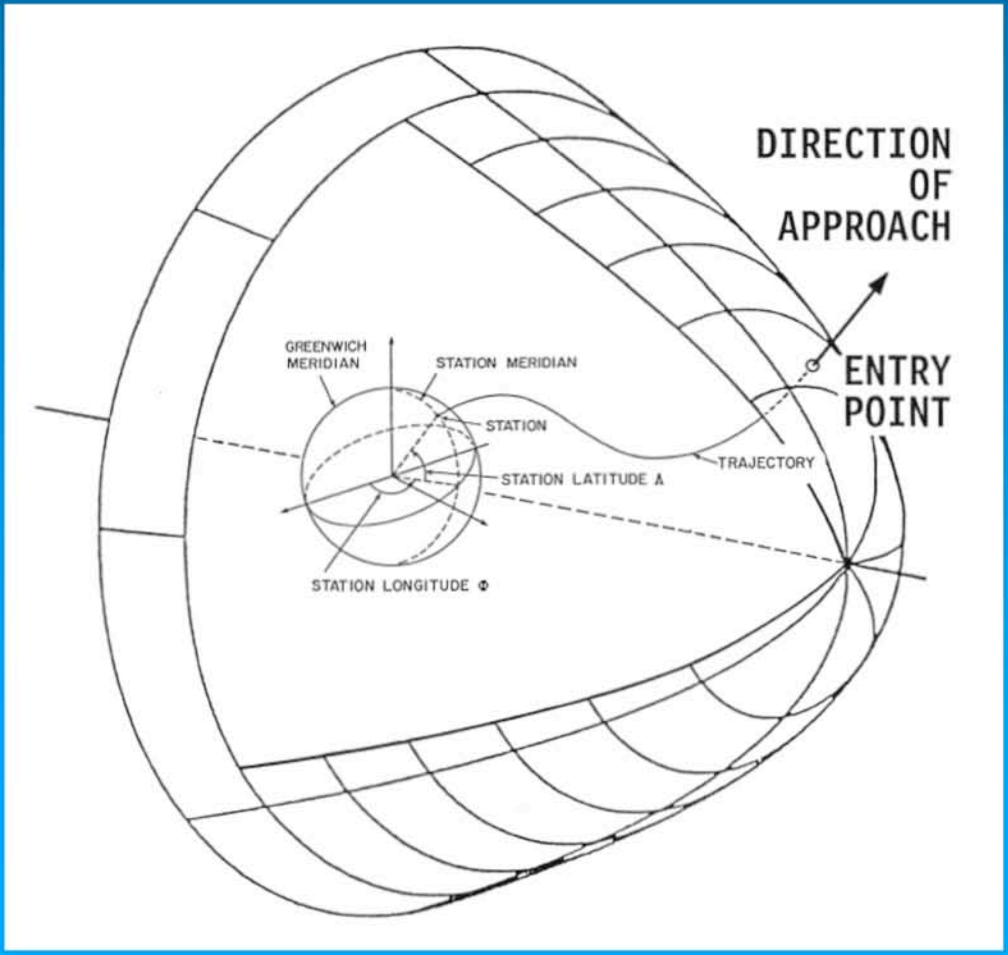
Distribution of GLEs for 5 solar cycles.

Paper 715, Shea & Smart

Geomagnetic Effects

Concept of Cutoff Rigidities and Asymptotic Viewing Directions

Technique: Trajectory tracing in a model of the magnetosperic magnetic field



Geomagnetic Effects

Magnetic field models:

Tsyganenko [1989] Planet. Space Sci., **37**, 5–20 (1989)

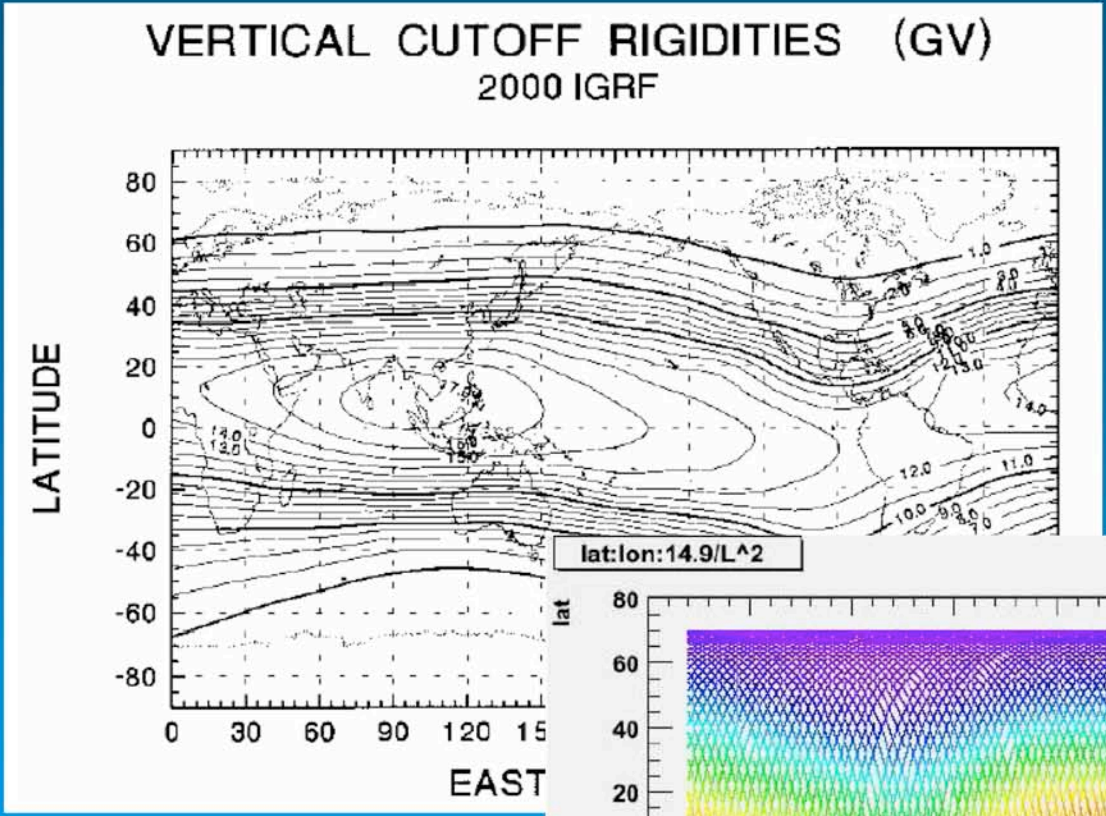
Boberg et al [1991], the ring current extension of Tsyganenko [1989] Geophys. Res. Lett., **22**, 9, 1133–1136 (1995)

Tsyganenko [1996] Proceedings of 3rd International Conference on Substorms, Versailles, France, ESA SP-389, 181–185, Eur. Space Agency, Paris (1996)

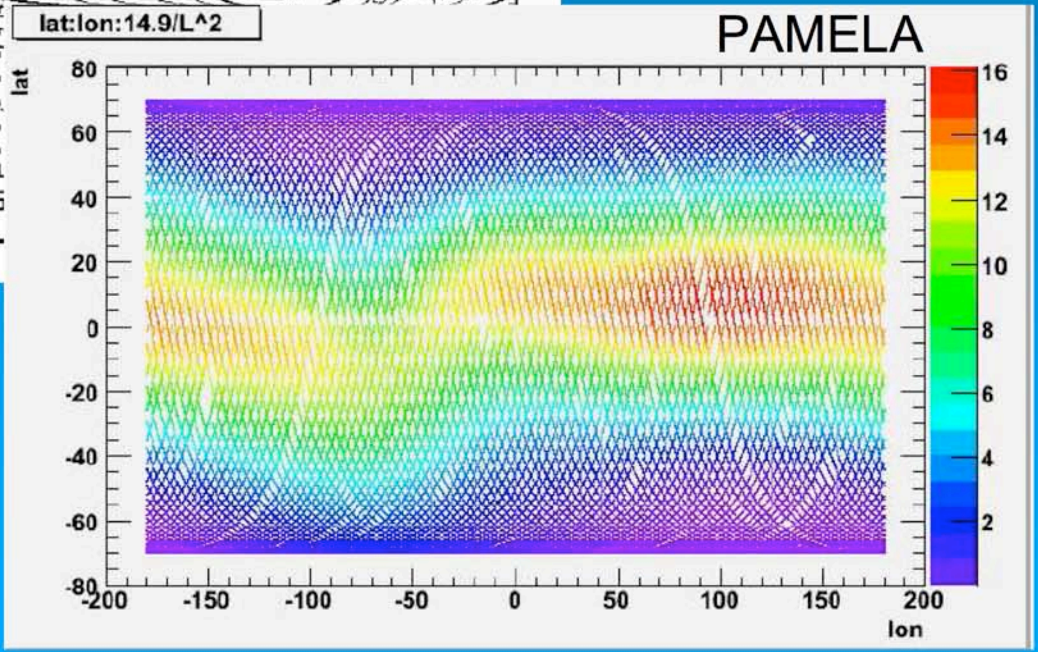
Tsyganenko and Stinov [2005] J. Geophys. Res., **110(A3)**, 3208 (2005)

Alexeev and Feldstein [2001] J. Atmos. Sol. Terr. Phys., **63**, 431–440 (2001)

Cutoff Rigidities



Paper 730
Smart & Shea

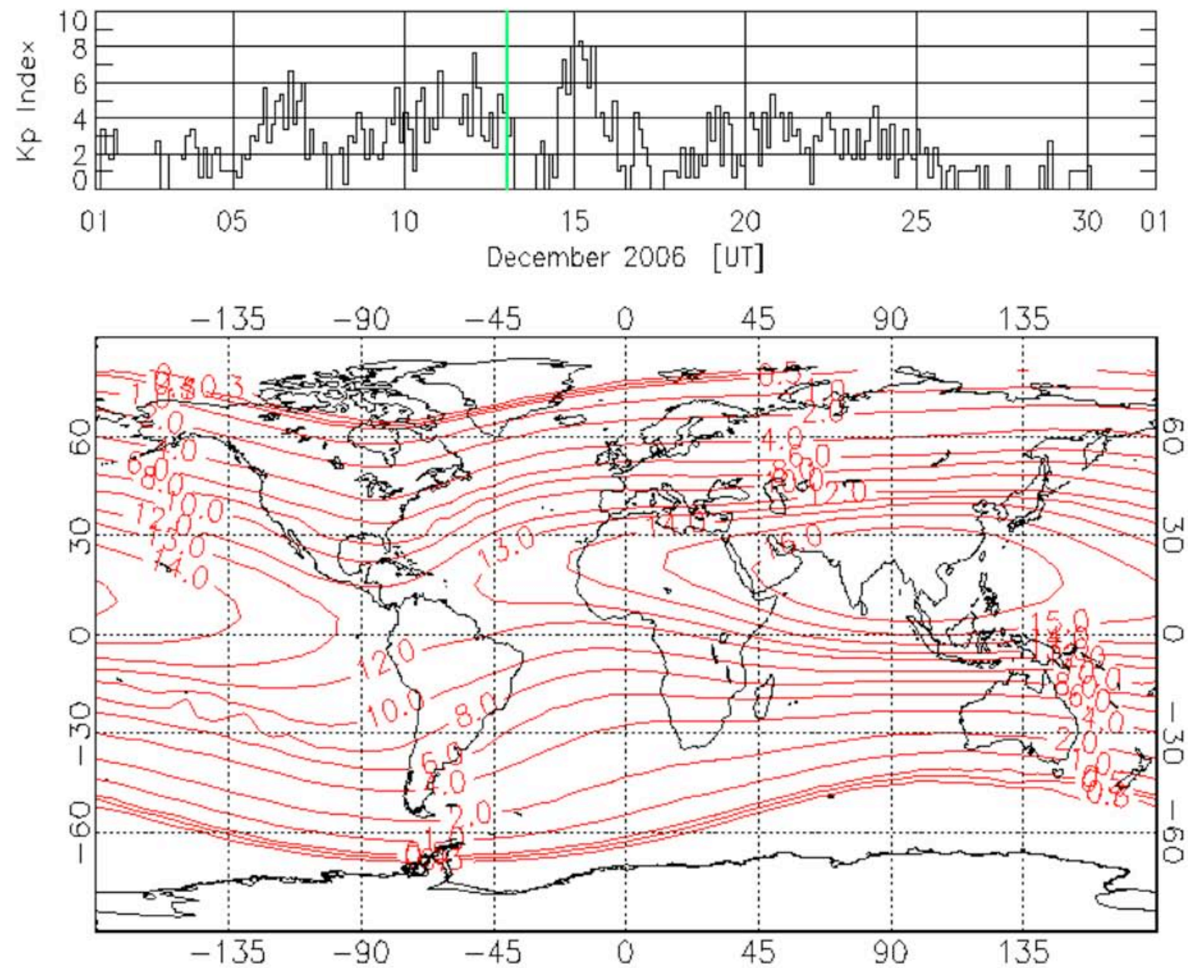


Paper 503
Casolino
& PAMELA Collaboration

See also Paper 340, Yushkov et al.

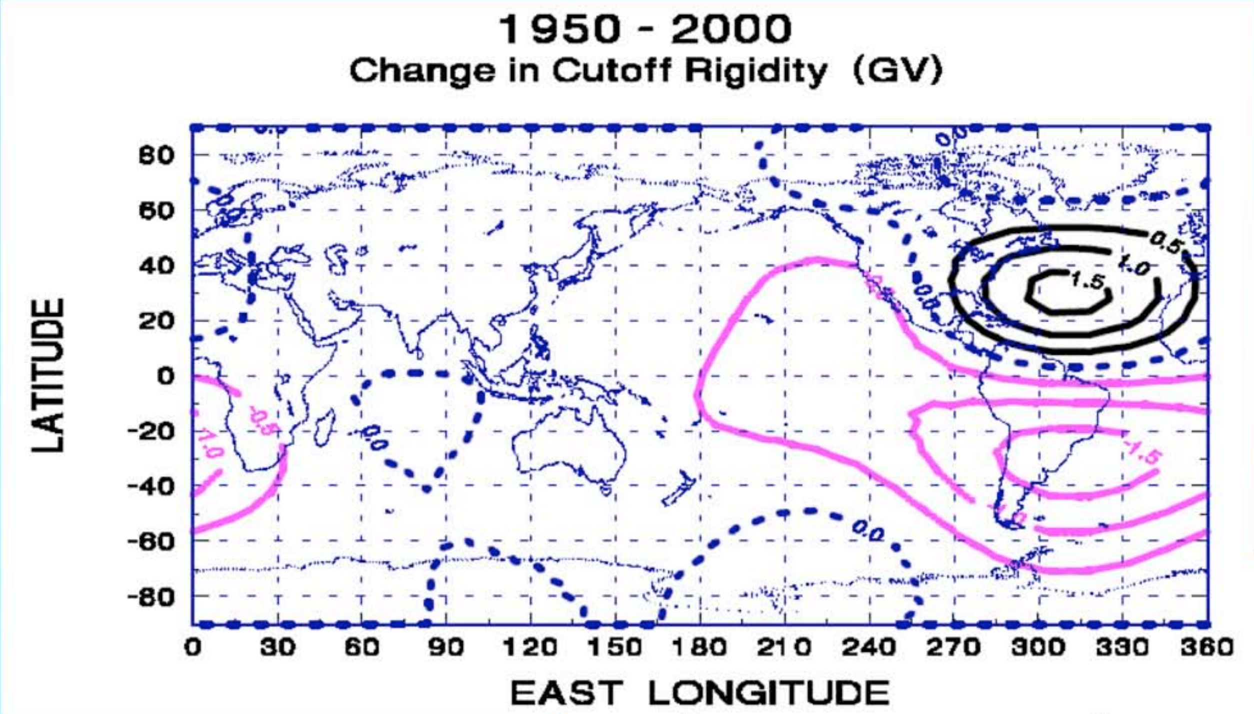
Near Real-Time Cutoff Rigidities

The December 2006 Geomagnetic Storm



Paper 1032, Bütikofer et al.

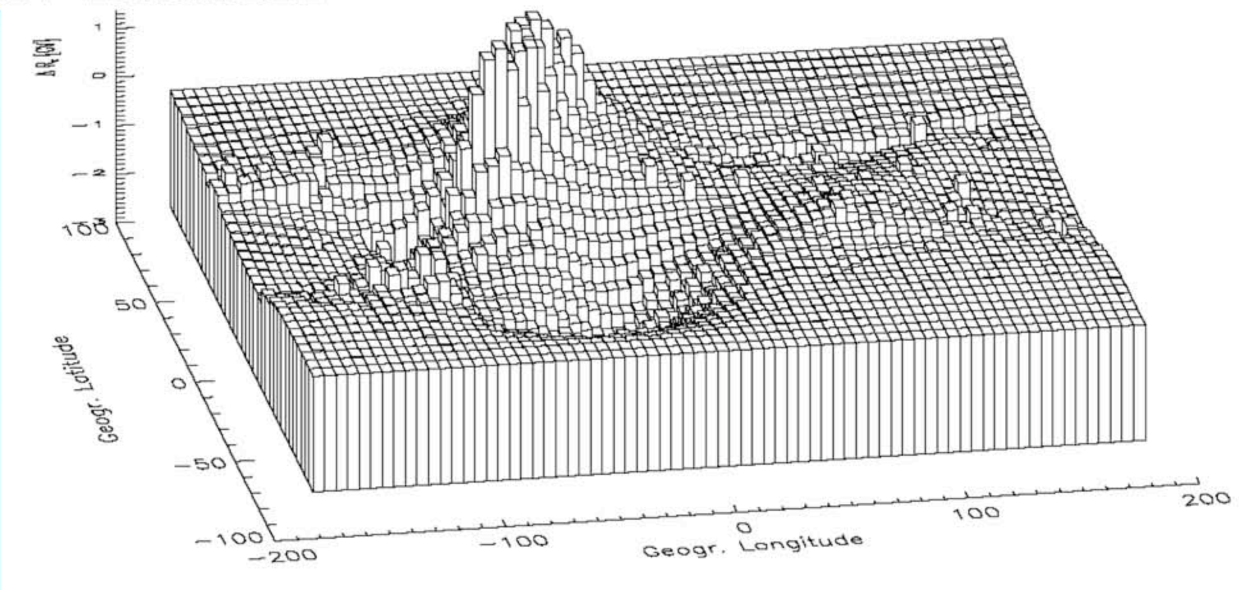
Secular Changes of Geomagnetic Field



Paper 730
Smart & Shea

Black indicates increase,
Red indicates decrease

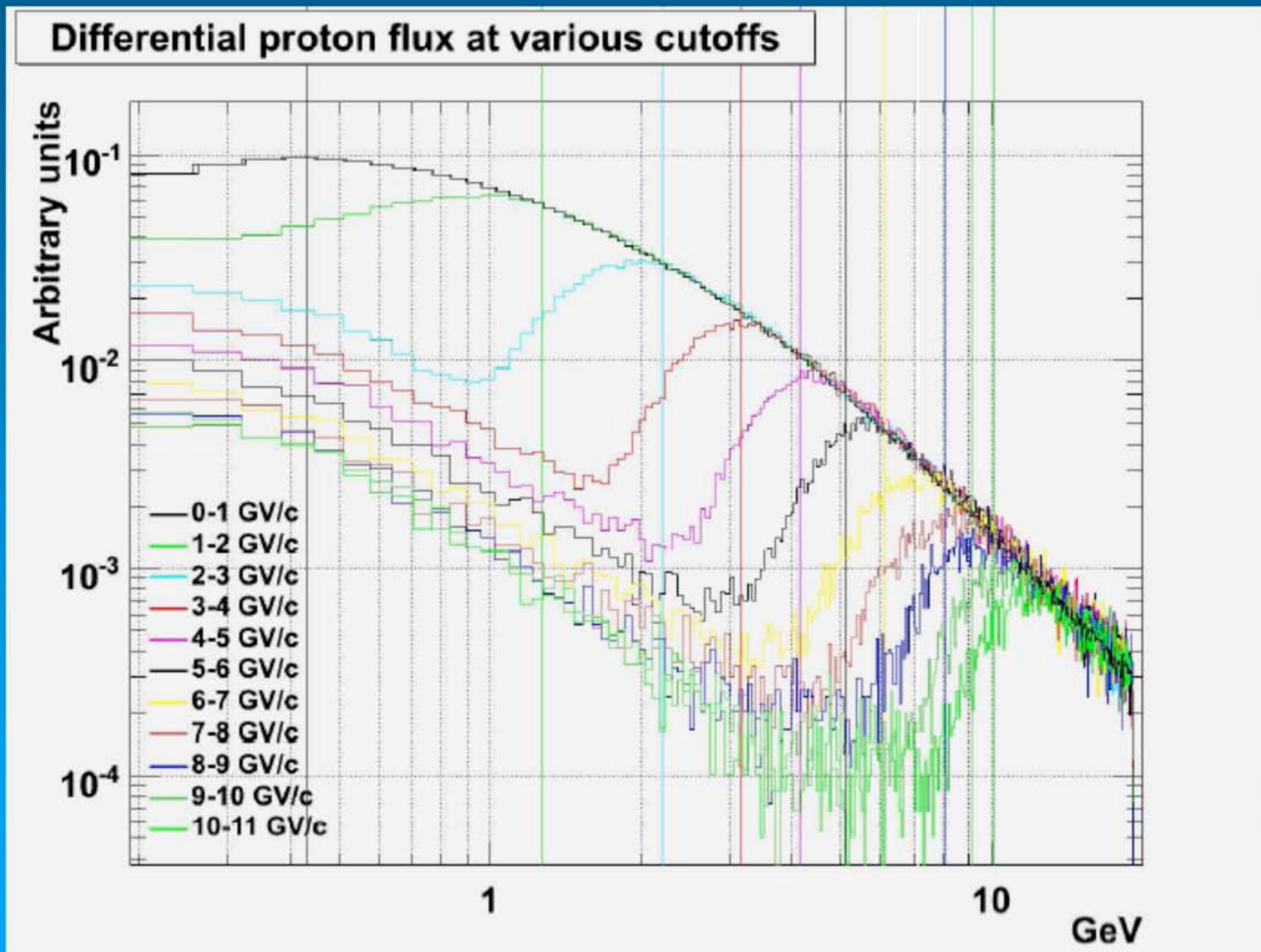
$R_c^{2005} - R_c^{1955}$



Paper 1032
Bütikofer et al.

In Situ Measurements with PAMELA

high inclination (70°), low Earth Orbit (350-600 km),



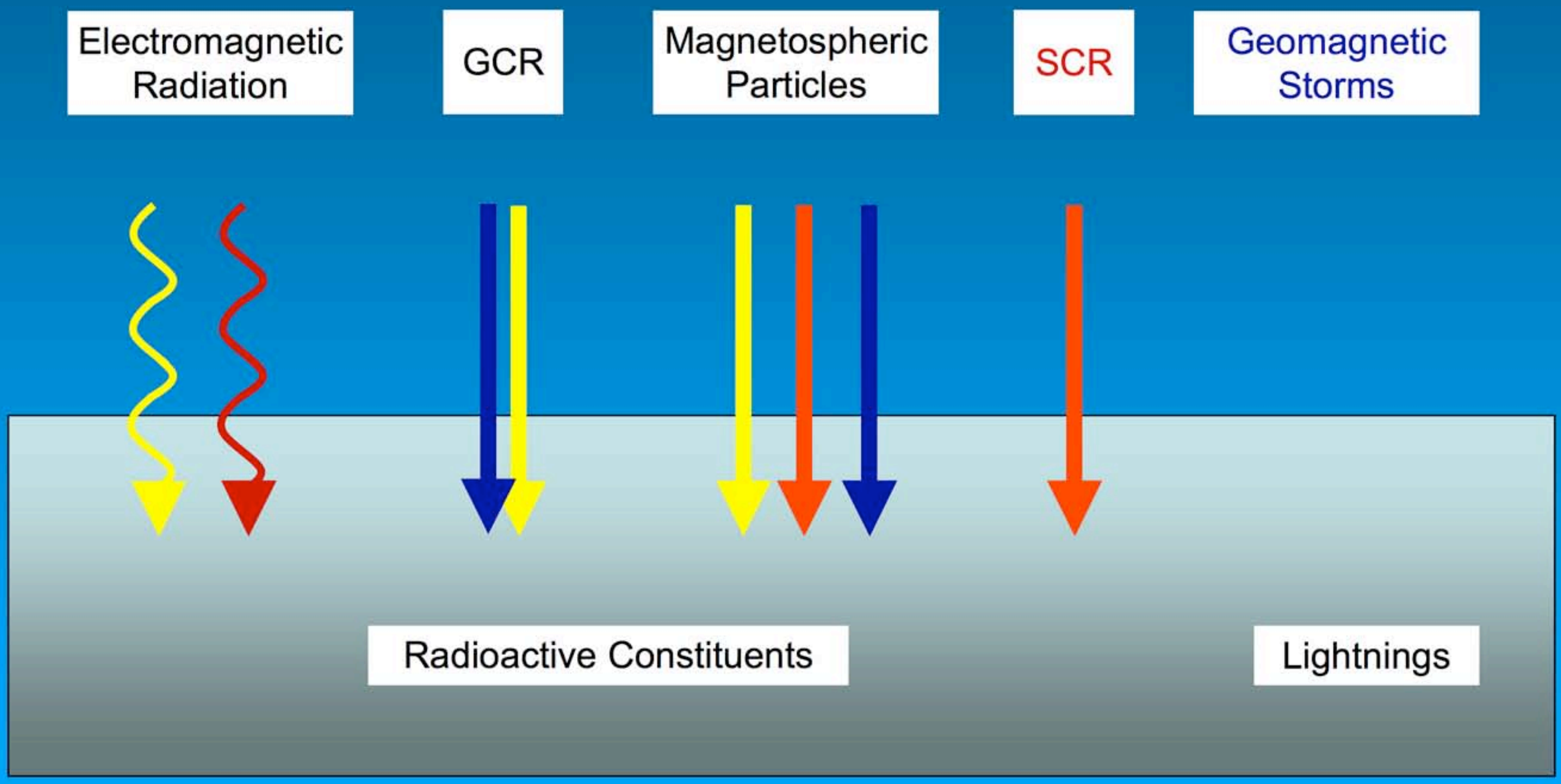
Confirms previous results by AMS

Paper 503, Casolino & PAMELA Collaboration

Effects in the Atmosphere

	Paper No	
Particle fluxes, Spectra	276, 315, 932(n), 966(n), 541(Temperature profile)	
Ionisation	433, 472, 916, 1083, 1222(Ozone hole)	
Radiation Dosis	376, 798	
Cosmic Rays and Clouds	1303	
Cosmogenic Nuclides	529, 1004	
	^{14}C	240
	^{7}Be	221, 224, 556, 559
Nitrates	718, 725	
E-Fields, Lightnings, Thunderclouds		265, 439, 447, 867, 1099
Hurricanes	321, 323, 1165	
Space Weather	260, 296	
Technical (Detectors, Calibration, Applications)		58, 849, 1000, 1093

Ion Production in the Earth's Atmosphere



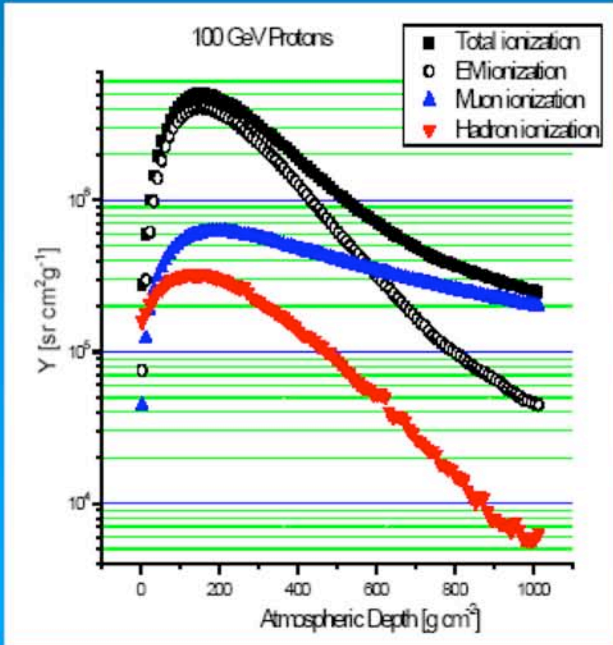
Europe - COST Action 724: "Developing the scientific basis for monitoring, modeling and predicting Space Weather"

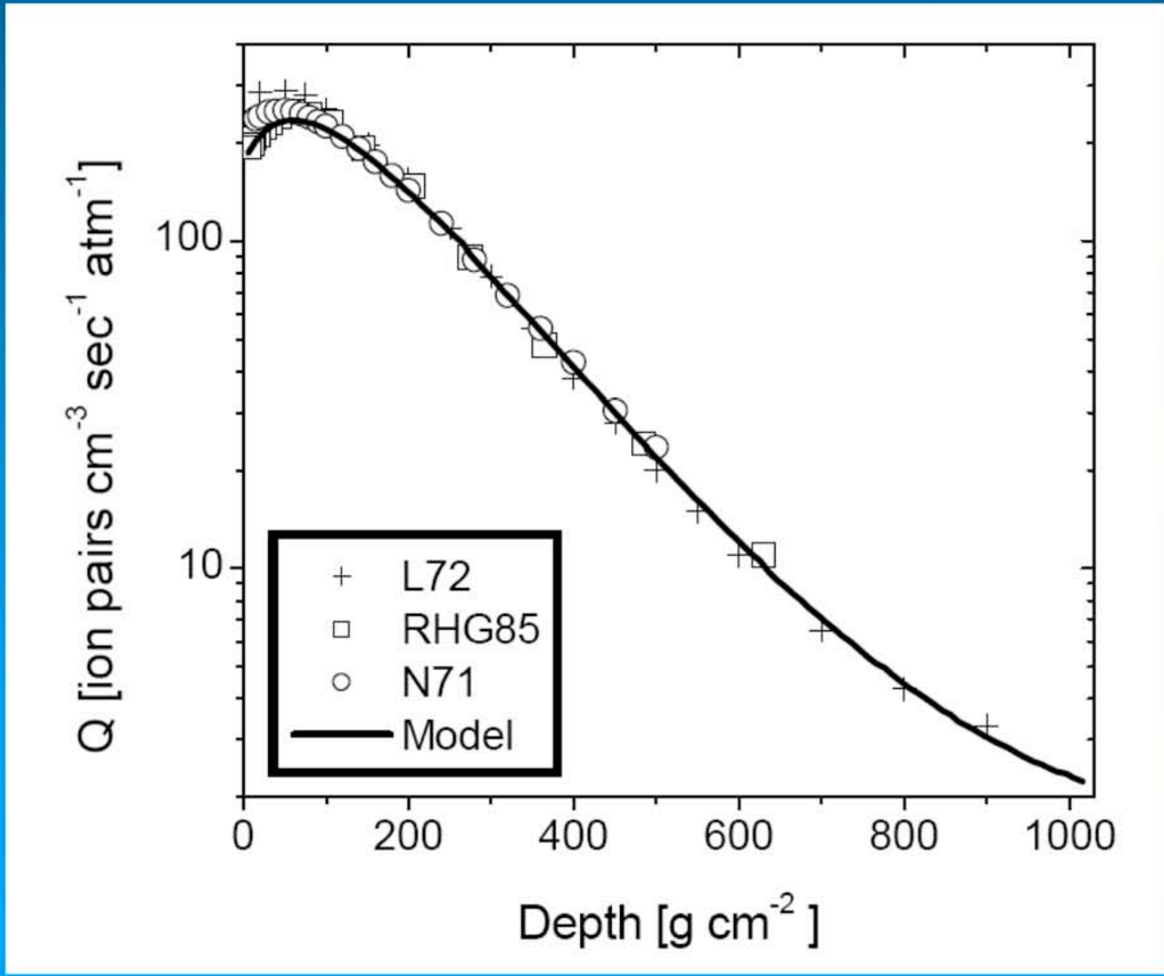
(COST = European Cooperation in the field of Scientific and Technical Research)

Oulu Model

Sofia Model

Bern Model



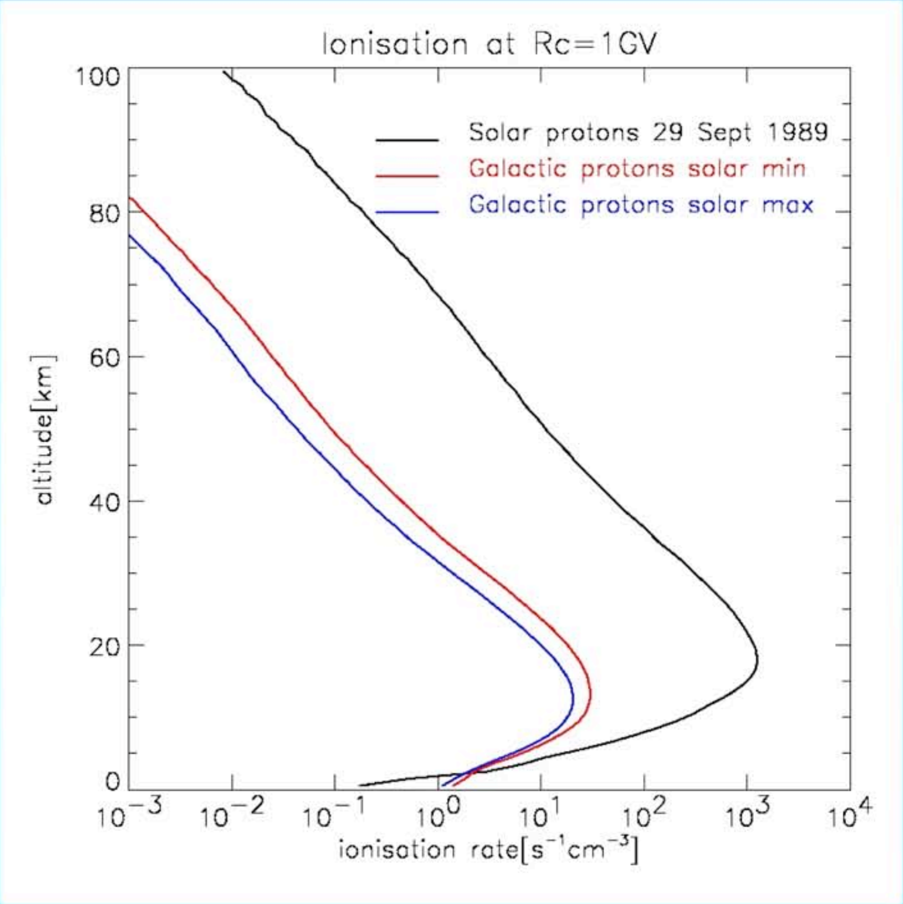


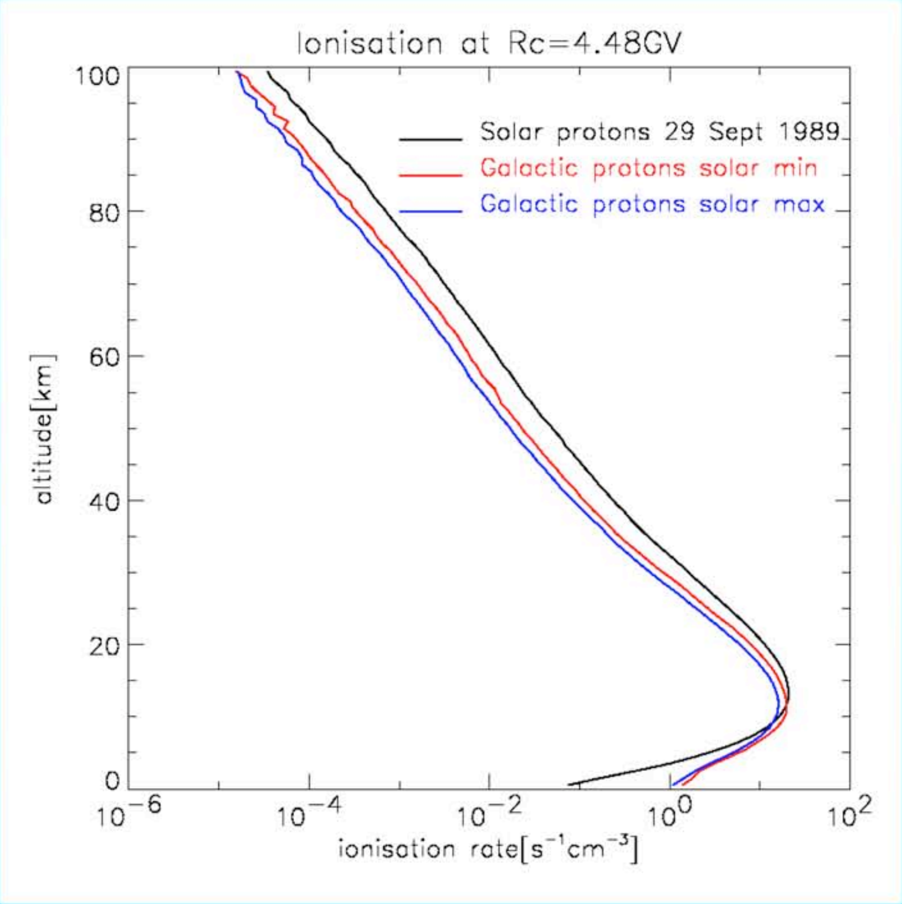
Paper 916, Velinov & Mishev

Paper 433, Usoskin & Kovaltsov

Ionization by SCR

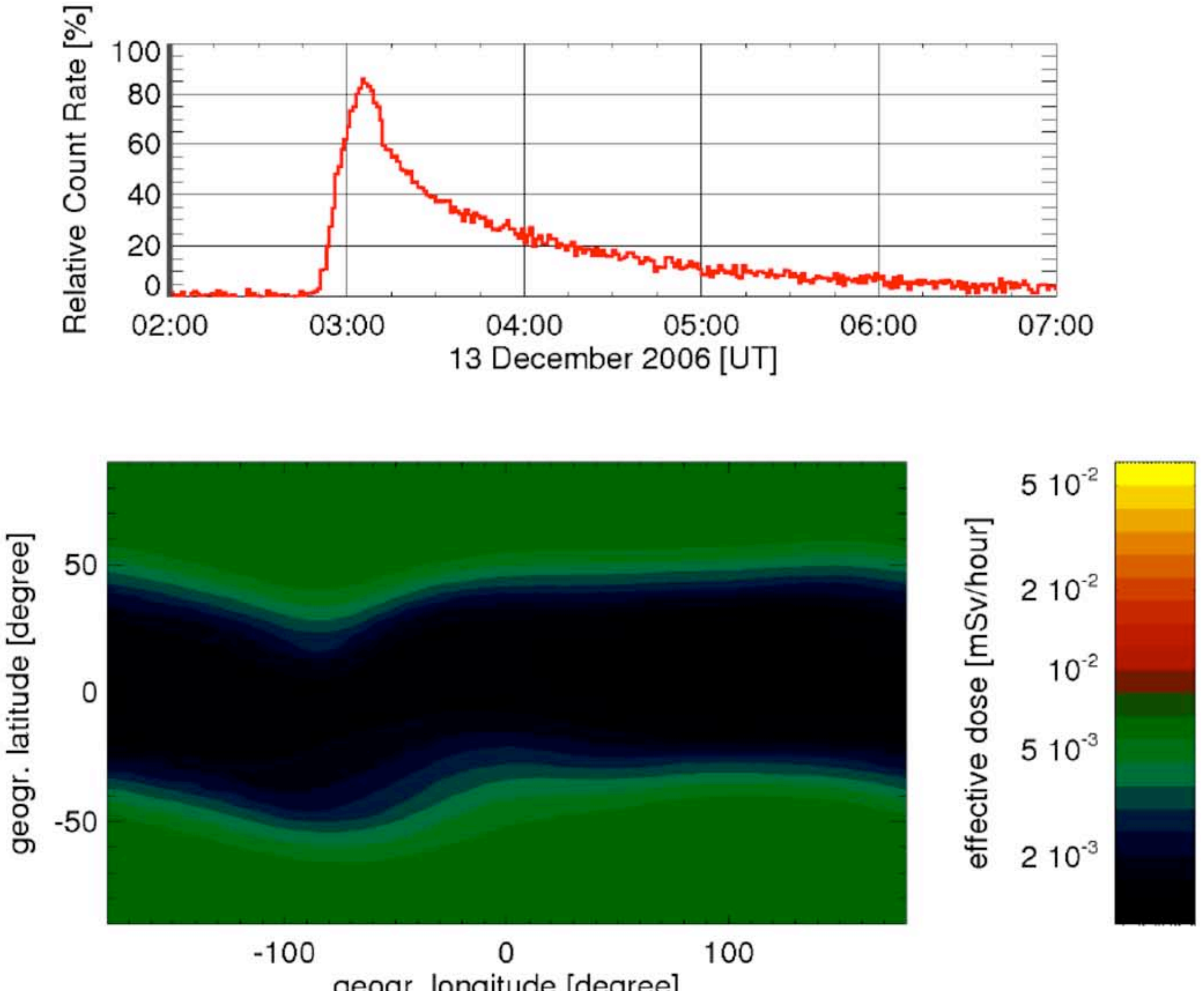
Bern Model: http://cosray.unibe.ch/~laurent/planetocosmics





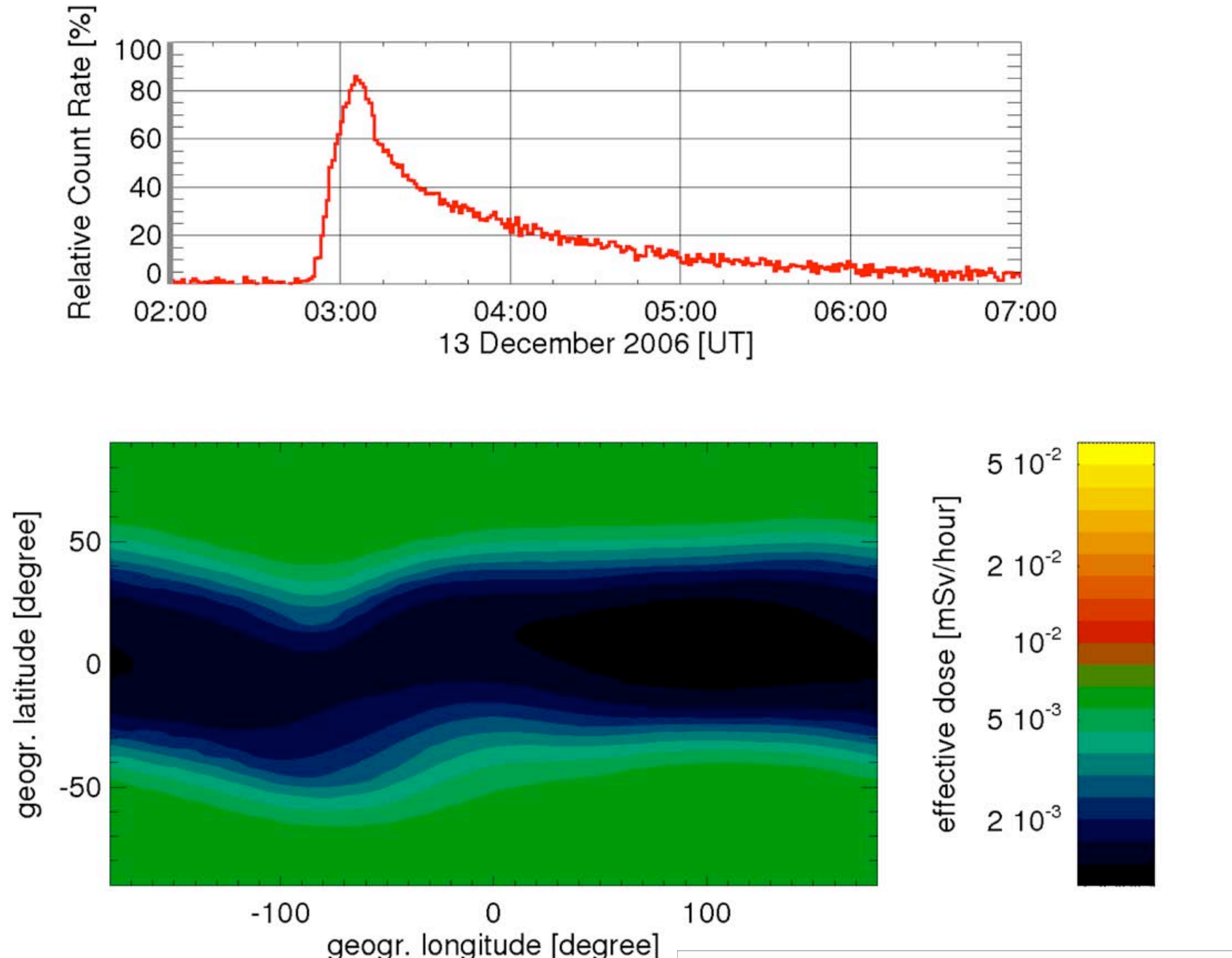
Desorgher et al., AOGS 2004

The 13 December 2006 Solar Particle Event Radiation Exposure at Aircraft Altitude



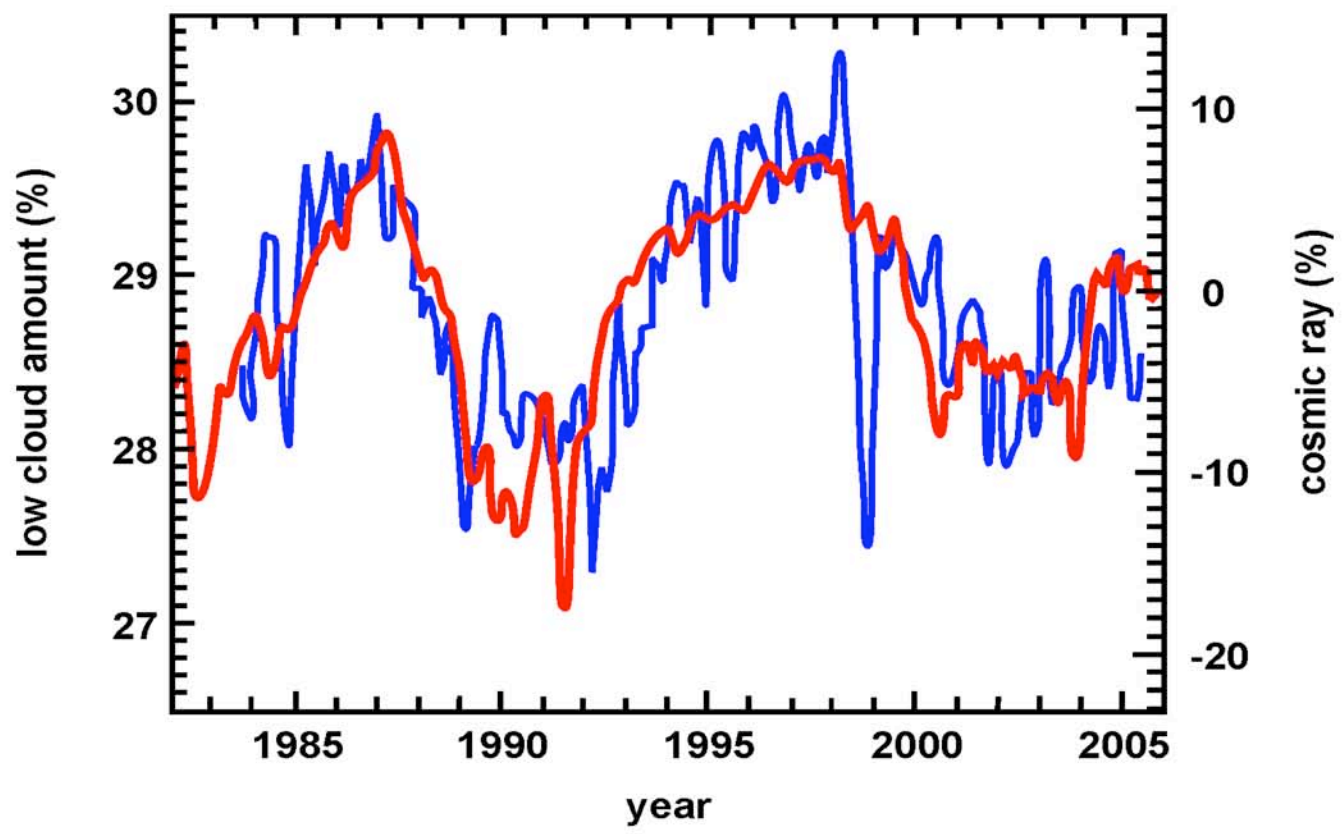
Flückiger et al., ICRC 2007 Workshop

The 13 December 2006 Solar Particle Event Radiation Exposure at Aircraft Altitude



Flückiger et al., ICRC 2007 Workshop

Cosmic Rays and Climate



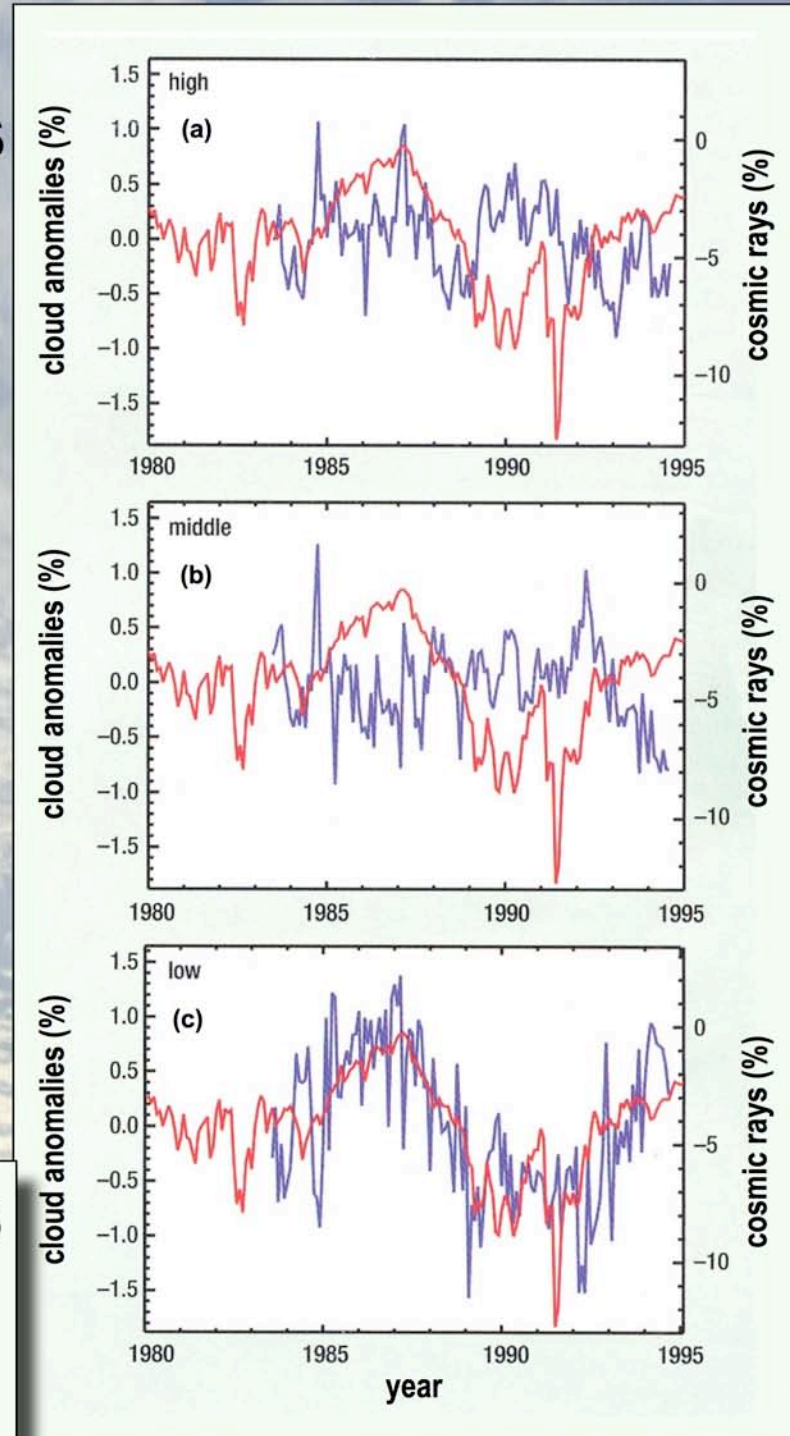
Low cloud cover anomalies and CR intensity (Huancayo) – Svensmark (2007)

Global monthly cloud anomalies (Svensmark, 2007)

a : high clouds (<440 h Pa)

b : middle (440 – 680 h Pa)

c : low (>680 h Pa)



Red Cosmic Rays (Huancayo)

Blue Cloud cover

Paper 1303, Sloan & Wolfendale

Ions as condensation centres for clouds ?

CR produce ~ 3 ion pairs $cm^{-3}s^{-1}$ in the lower atmosphere. Lifetime is $\simeq$ 50sec, so ~ 150cm^{-3}. Clouds have ~ 100 droplets cm^{-3} so a link would appear to be obvious.

But

Supersaturations in atmosphere far too low for ions to be at an advantage. Aerosols (salt particles, dust, industrial emissions…) dominate. Sizes $\approx 10^{-1}\mu(10^{\pm 2})$.

Paper 1303, Sloan & Wolfendale

Evidence from radioactive ‘events’

Chernobyl

April 26, 1986
≈ 2 Mt of fall-out.
No increase in cloud cover.
η(ions → cloud droplets) $\lessapprox$ 3%

Paper 1303, Sloan & Wolfendale

Nuclear Bomb Tests

Eg. **BRAVO -**

Bikini Atoll, March 1, 1954.

~ 15 Mt

radioactive particles, 10 - 100μ

300 miles from Ground Zero, dose rate
~ 100 Rh^{-1}, after 4 days.
Yields 5.10^7 ions $cm^{-1}s^{-1}$

Averaging over space and time and allowing for size distribution yields.

$\eta \lesssim 10^{-4}$

Paper 1303, Sloan & Wolfendale

Tentative Conclusions

1. CR contribution to 11-year cycle variability of mean global temperature $\lesssim$ 15%.

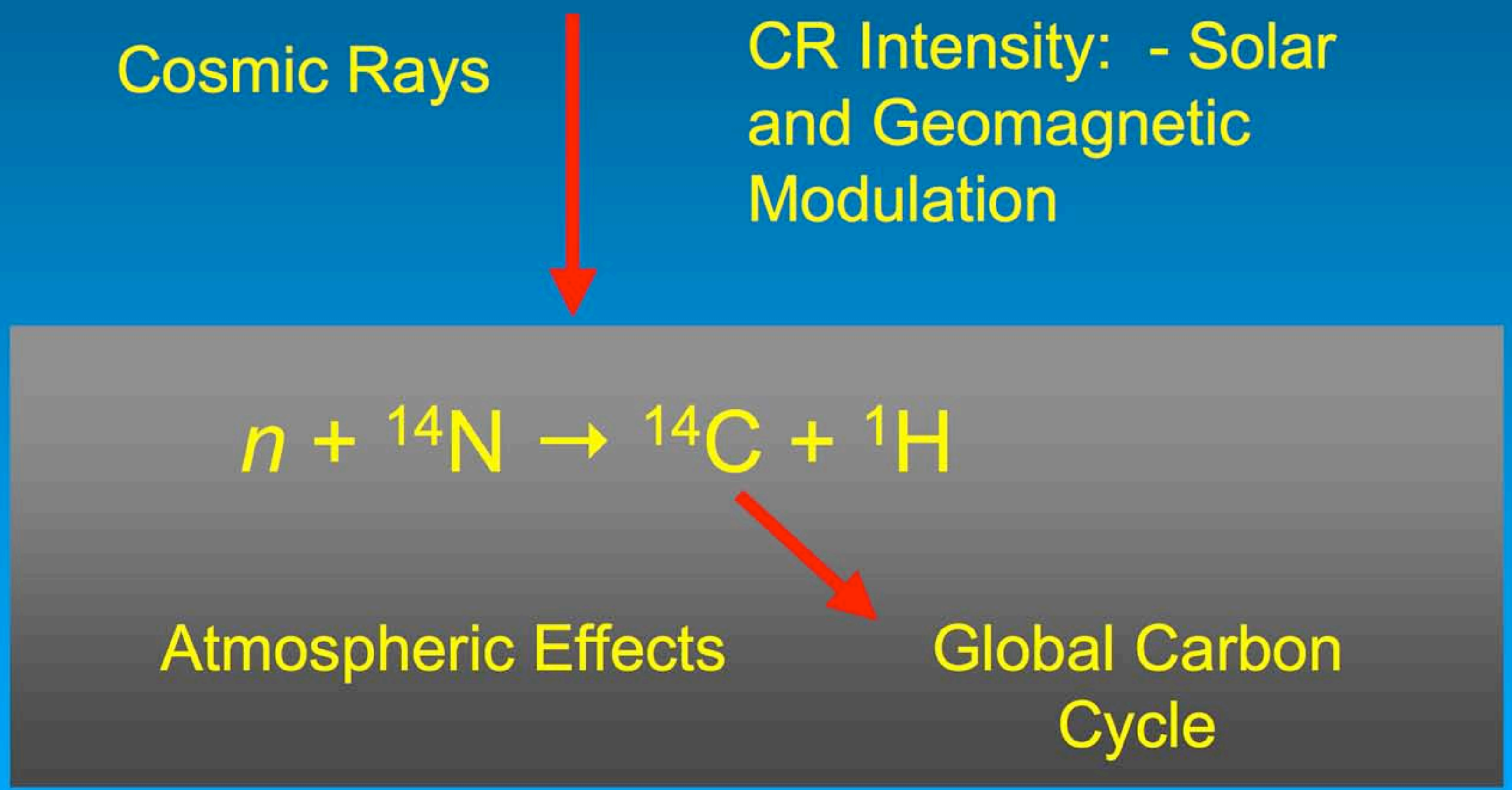
2. CR contribution to slow increase of mean global temperature over last 35 years $\lesssim$ 1%.

Paper 1303, Sloan & Wolfendale

Cosmogenic nuclides, Nitrates, Cosmic Rays and the Sun

	Paper No	
Cosmogenic Nuclides	**Highlight Paper by K.G. McCracken**	
	529, 1004	
	^{14}C	240
	^{7}Be	221, 224, 556, 559
Nitrates	718, 725	

^{14}C



Cosmic Rays
CR Intensity: - Solar and Geomagnetic Modulation
$n + {}^{14}N \rightarrow {}^{14}C + {}^{1}H$
Atmospheric Effects
Global Carbon Cycle

^{10}Be, ^{7}Be

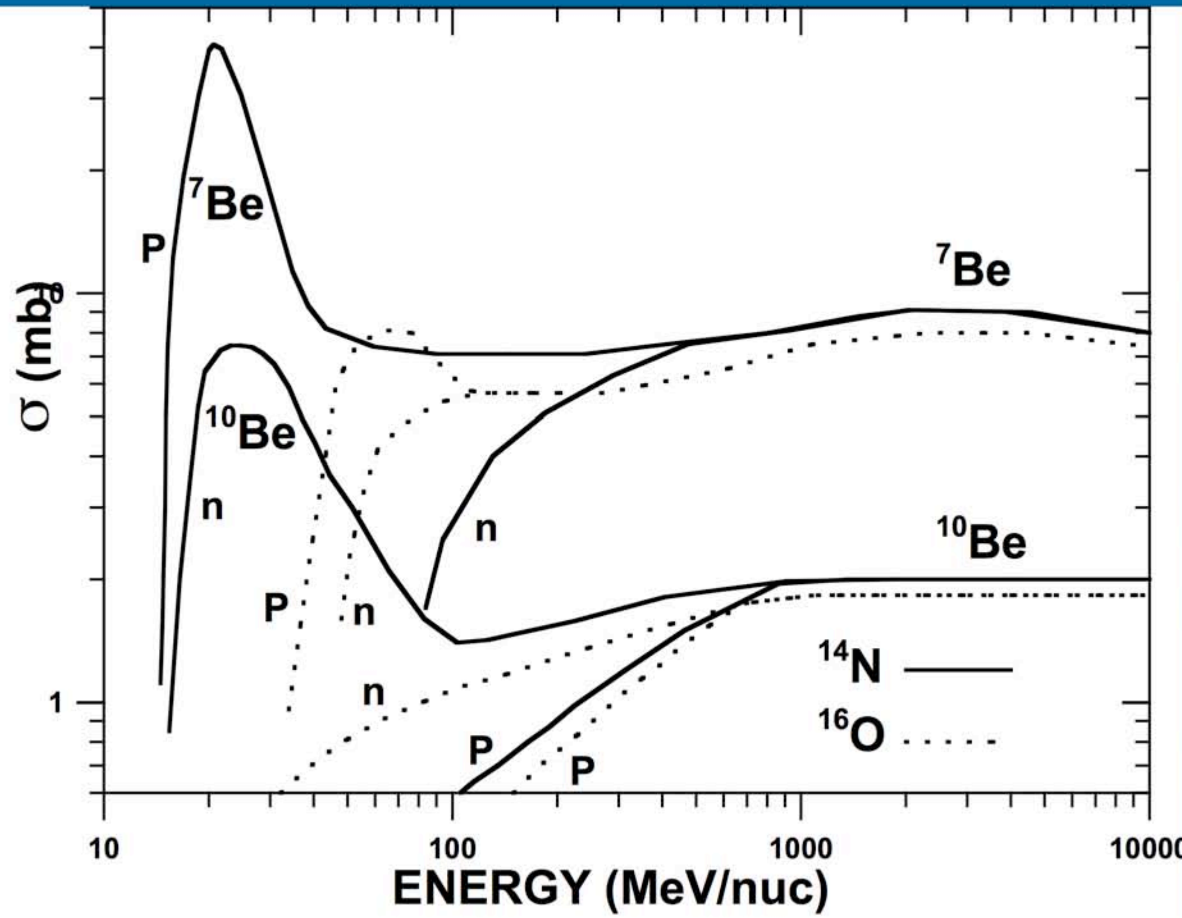
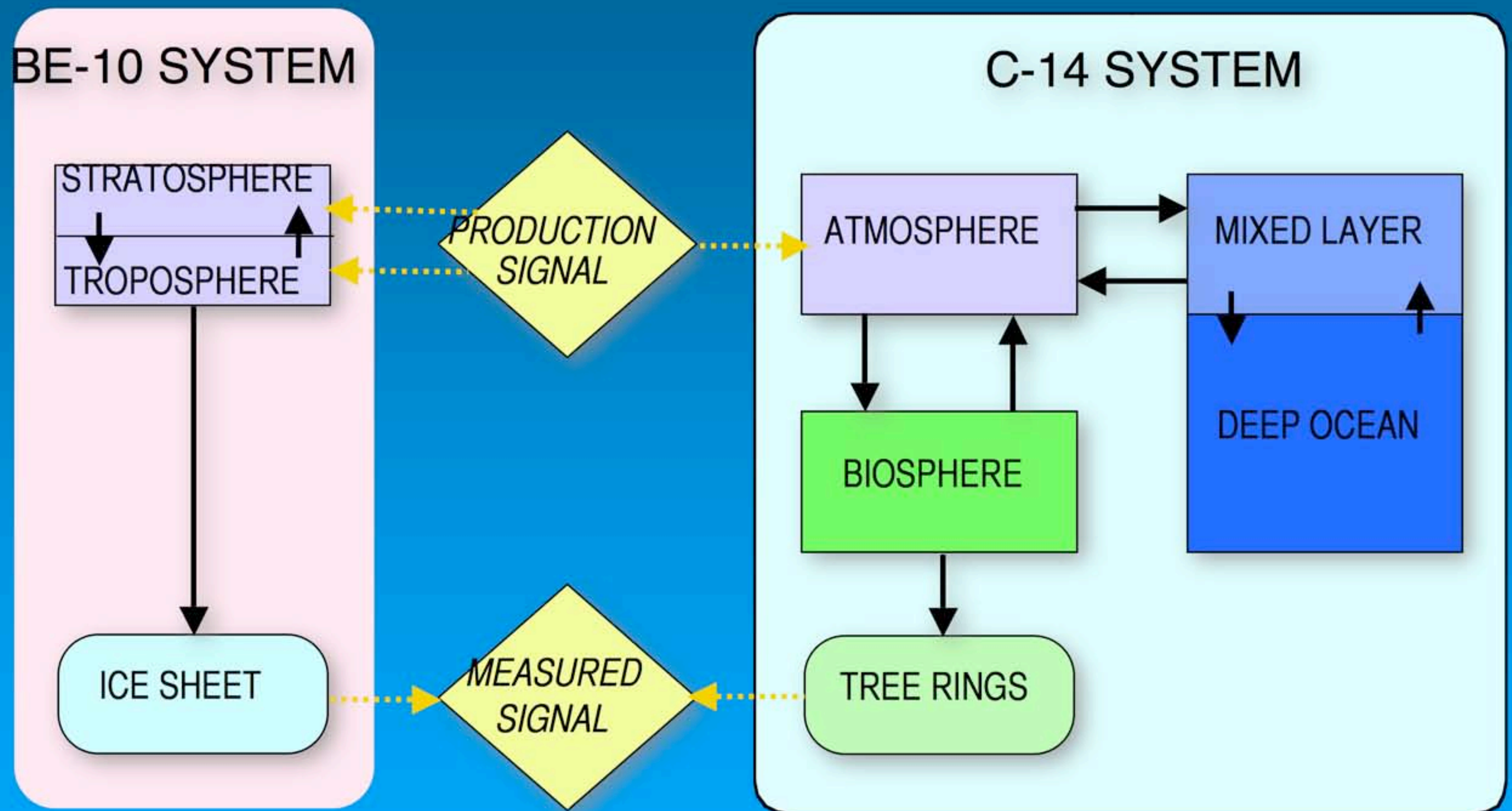


FIGURE 2

Properties of cosmogenic radionuclides (Masarik and Beer, 1999)

Nuclide	Half-life (yr)	Targets	Prod. rate ($cm^{-2}s^{-1}$)
^{10}Be	1.51×10^6	N, O	0.018
^{14}C	5730	N	2.0
^{36}Cl	3.08×10^5	Ar	0.0019

Comparison ^{10}Be - ^{14}C



Paper 1004, Beer & McCracken

Cosmogenic nuclide Be-7 and aerosols

- Production

$^{14}N(n,x)^{7}Be$
$^{14}N(p,x)^{7}Be$
$^{16}O(n,x)^{7}Be$
$^{16}O(p,x)^{7}Be$
$^{40}Ar(n,x)^{7}Be$
$^{40}Ar(p,x)^{7}Be$

Cosmic rays collide with the atmospheric elements

↓

Be-7 is produced

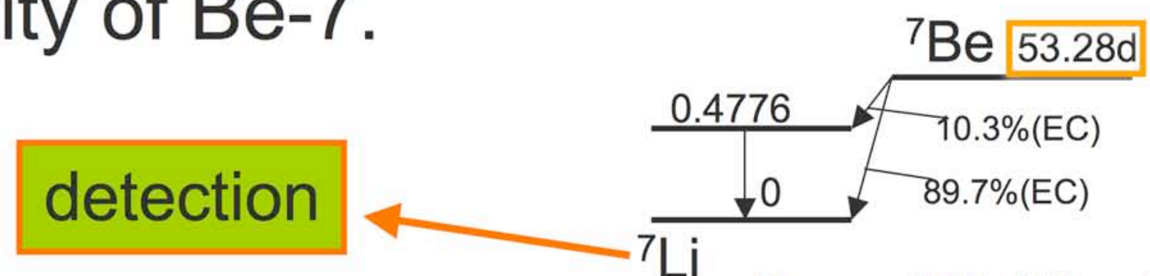
↓

Be -7 is oxidized and attaches to aerosols.

↓

Aerosols with Be-7 fall down to the ground.

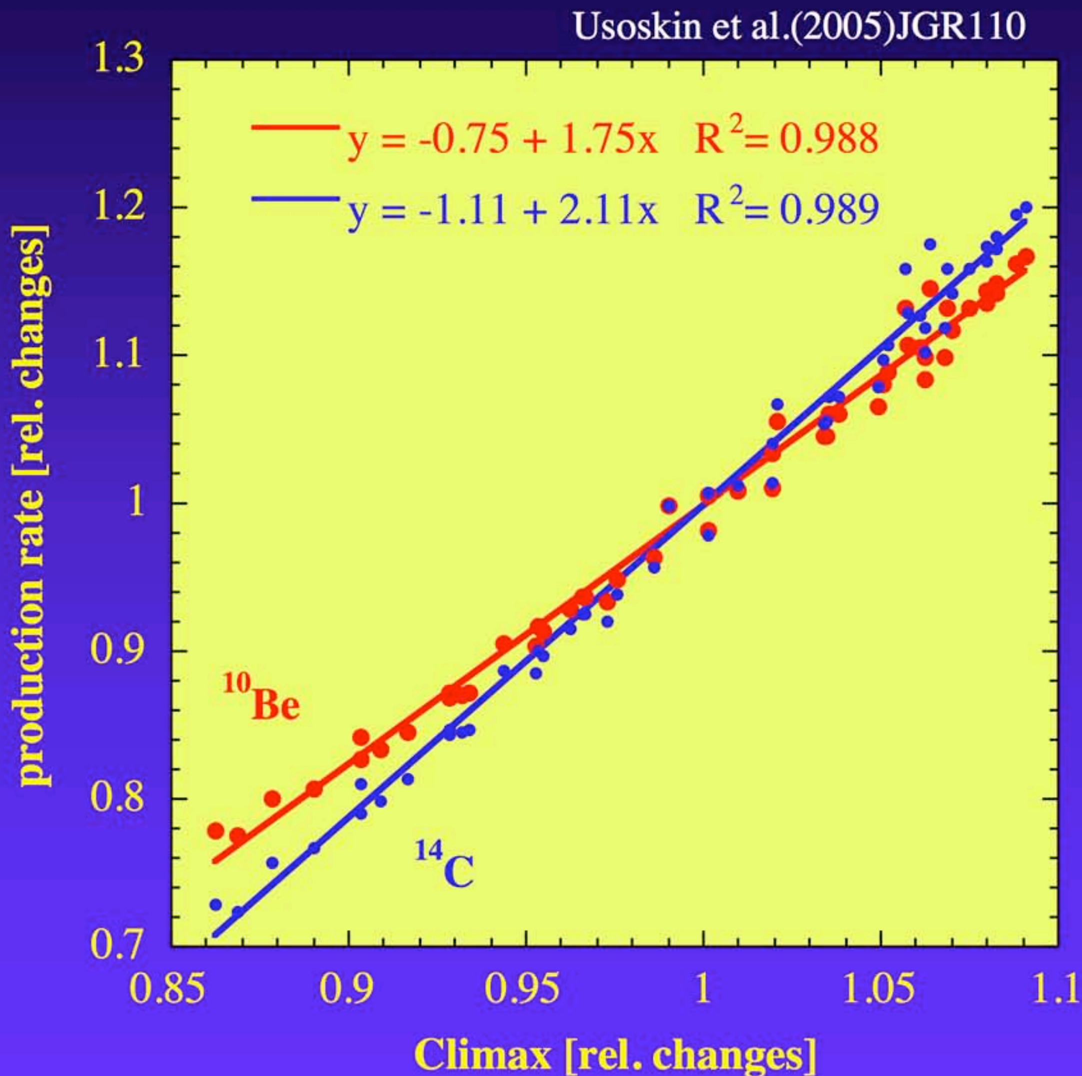
- We collect the aerosols and measure the radioactivity of Be-7.



Gamma ray: 477 keV

Paper 559, Kikuchi et al.

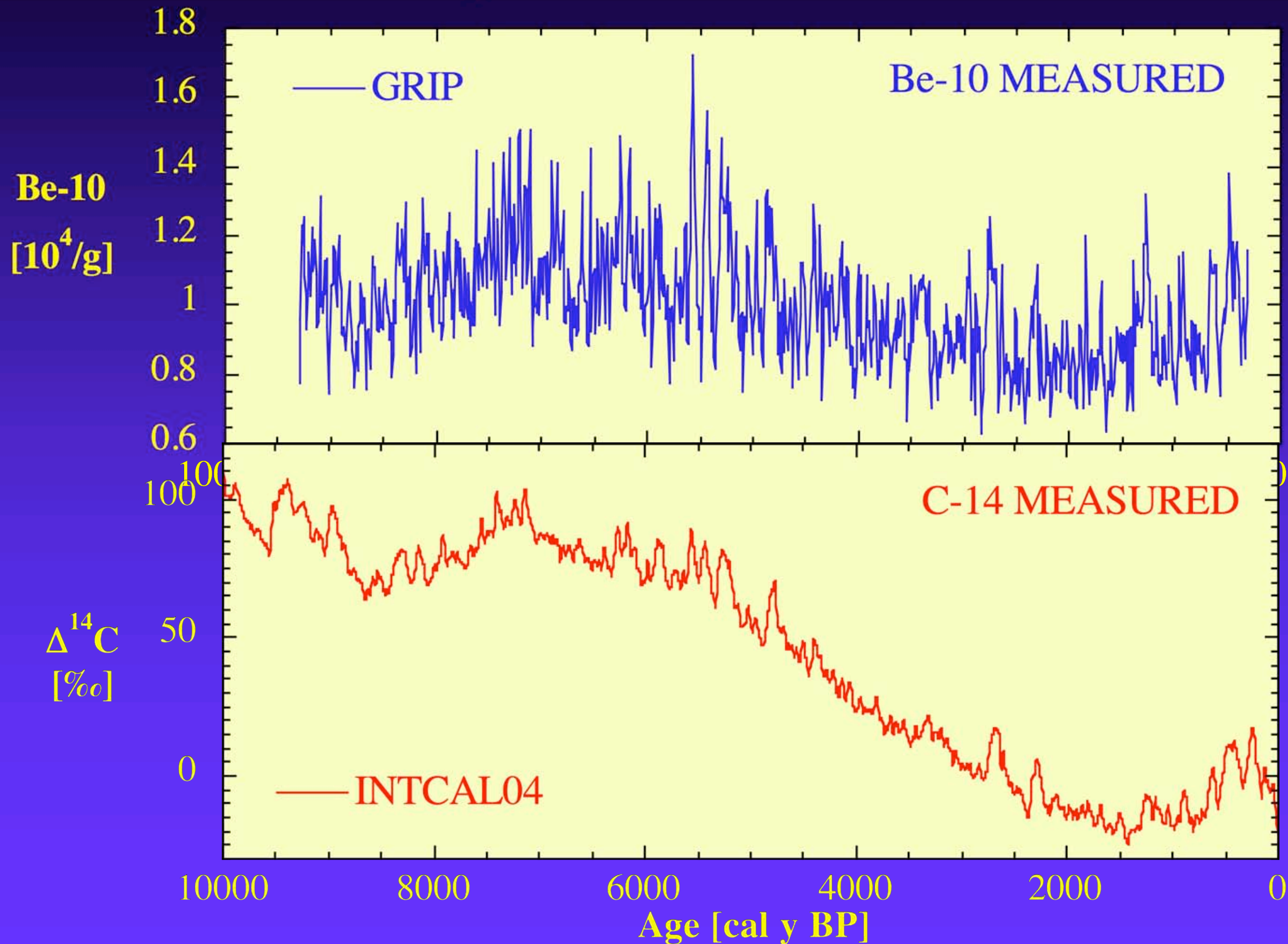
Comparison: Climax - ^{10}Be & ^{14}C



Paper 1004, Beer & McCracken

Paper 1004, Beer & McCracken

Measured Signals

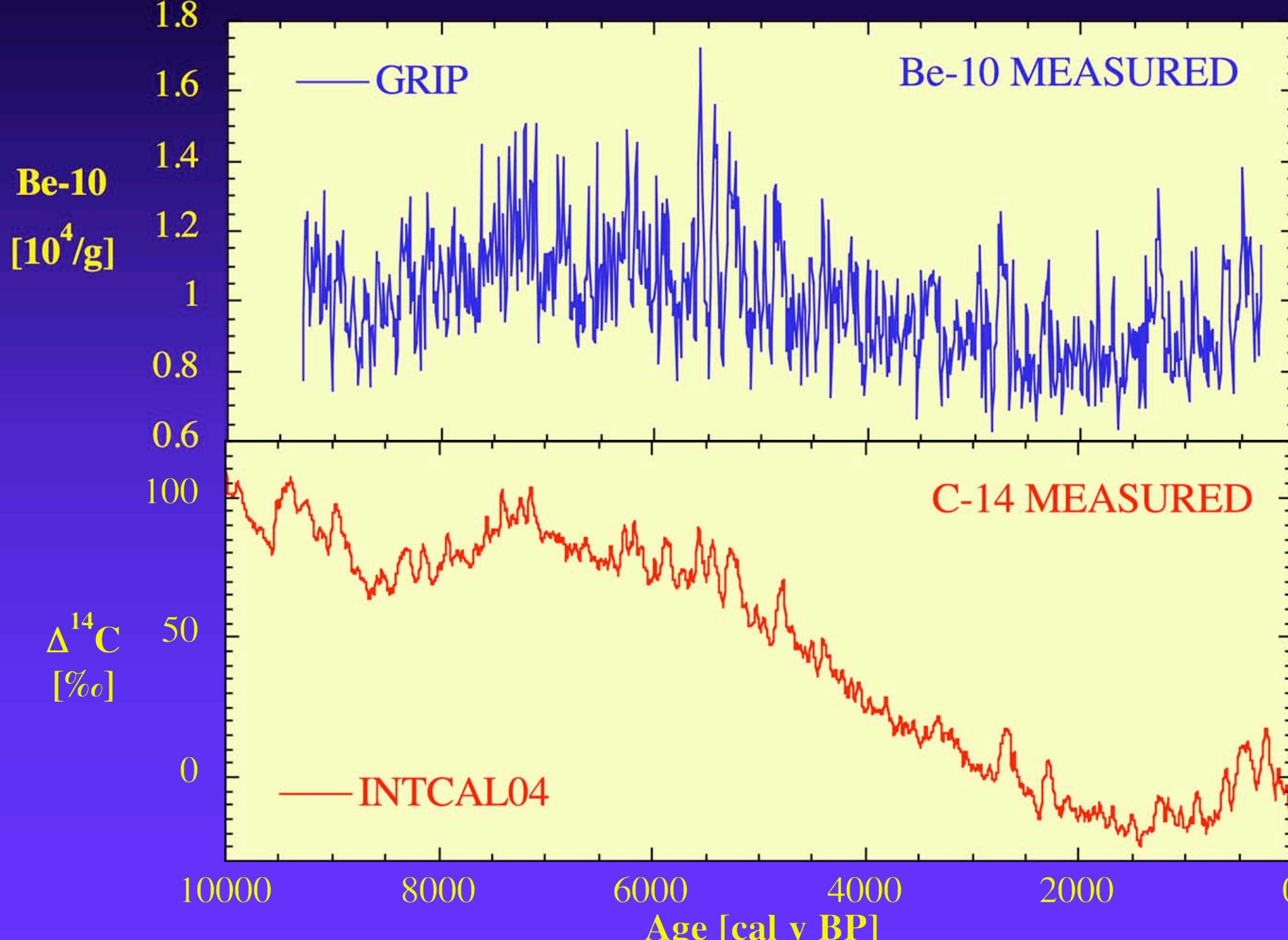


ICRC2007
Merida
5.7.2007
Jürg Beer

eawag
aquatic research

Paper 1004, Beer & McCracken

Measured Signals



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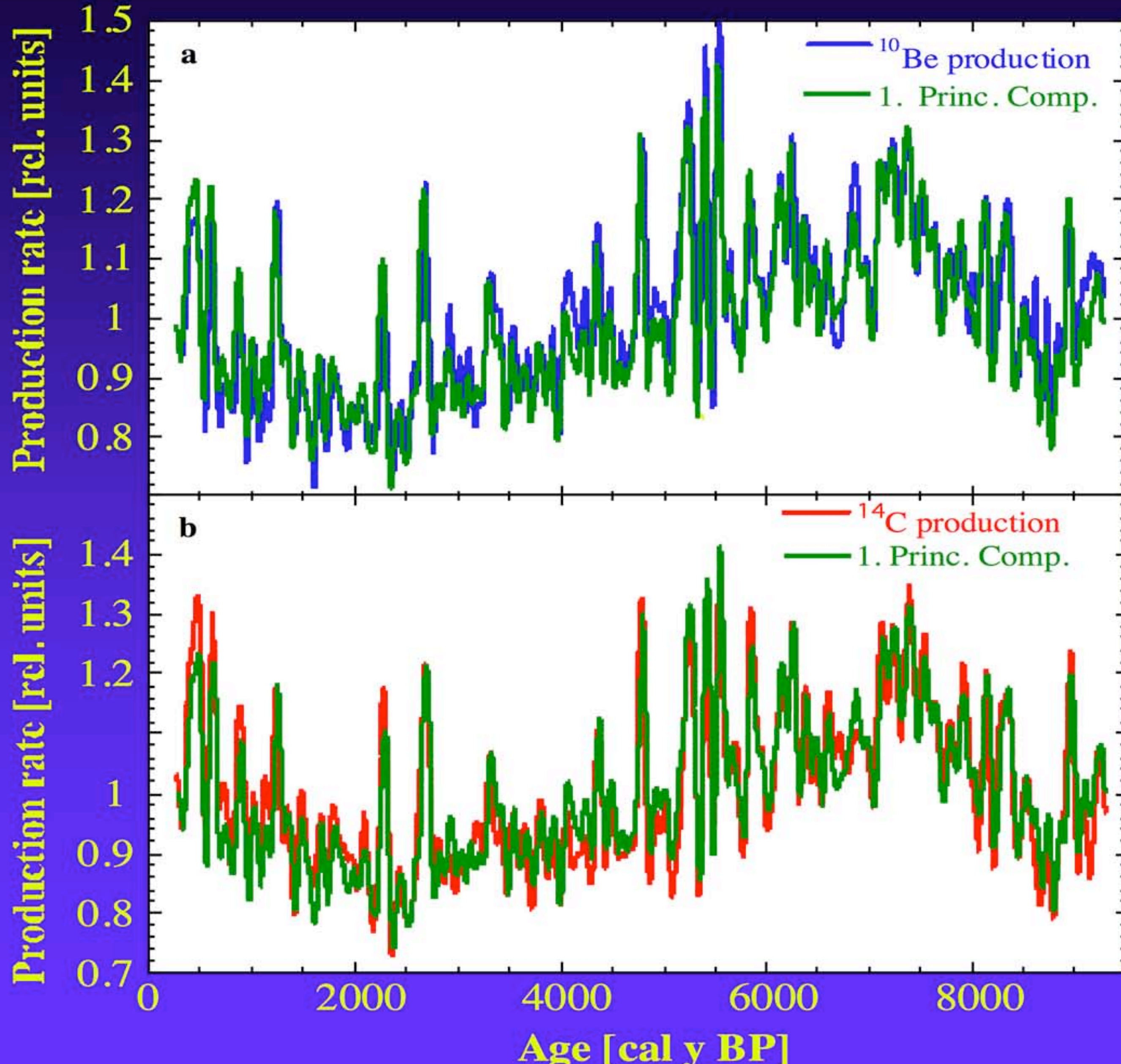
First Principal Component



ICRC2007
Merida
5.7.2007
Jürg Beer

Conclusions

- Cosmogenic Radionuclides (^{10}Be, ^{14}C)
  - New type of Neutron Monitor
  - Temporal resolution: >1 year
  - Signal to noise ratio: 9:1 (100 y time scale)
  - Time range:
    - today: 10'000 years
    - future: 40'000 years (^{14}C in trees)
      1000'000 years (^{10}Be in ice)

Paper 1004, Beer & McCracken

Nitrates

SOLAR PROTONS PROVIDE THE ENERGY TO DRIVE AN ENDOTHERMIC REACTION

$NO + O_3$ ♉ $NO_2 + O_2$

$NO_2 + O$ ♉ $NO + O_2$

\- - - - - - - - - - - - - - - - -

Net: $O_3 + O$ ♉ $O_2 + O_2$

"odd nitrogen" (complex of nitrate radicals designated by the symbol NO_y)

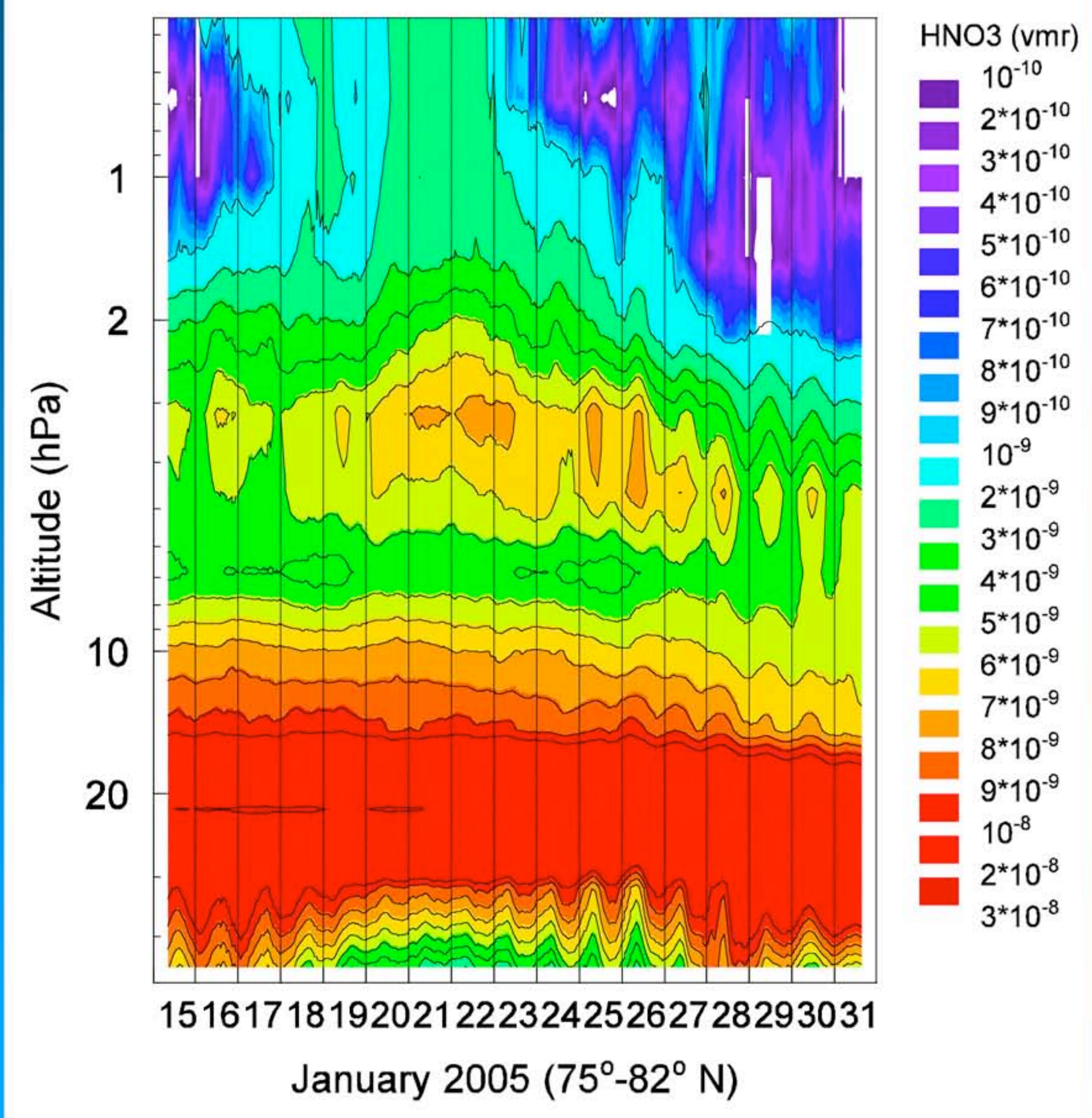
Nitrate deposition in polar ice are markers of the HNO_3 precipitation.

Contemporary state-of-the-art measurements of the denitrification of the polar atmosphere find significant nitric acid trihydrate particles (called NAT rocks) in the polar stratospheric clouds.

Some of the HNO_3 is transported to the troposphere, where it is precipitated downward to the surface.

Paper 725, Kepko et al.

HNO_3 (a good proxy for NOy): **15-31/01/2005**



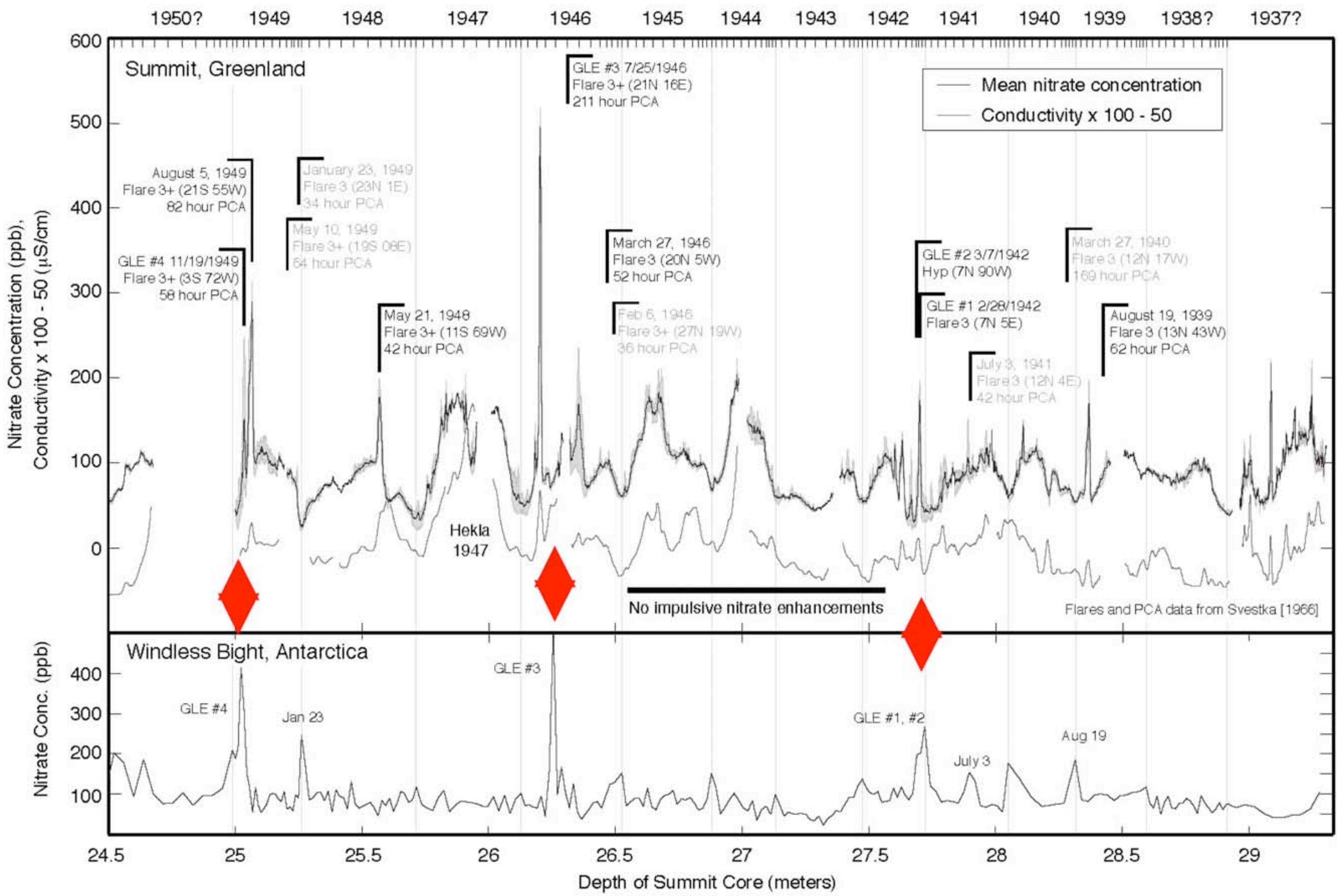
Contours of averaged HNO_3 (volume mixing ratio) values during the second part of January 2005).
Selected location: ~ 75°-82°N.

The HNO_3 increase can be the result of:

- the OH and NO_2 raise during SEP events;
- through the reaction of water cluster ions with NO_3 .

Paper 1009, Storini & Damiani

Observations of Impulsive Nitrate Enhancements Associated With Ground-Level Cosmic Ray Events 1-4 (1942-1949)

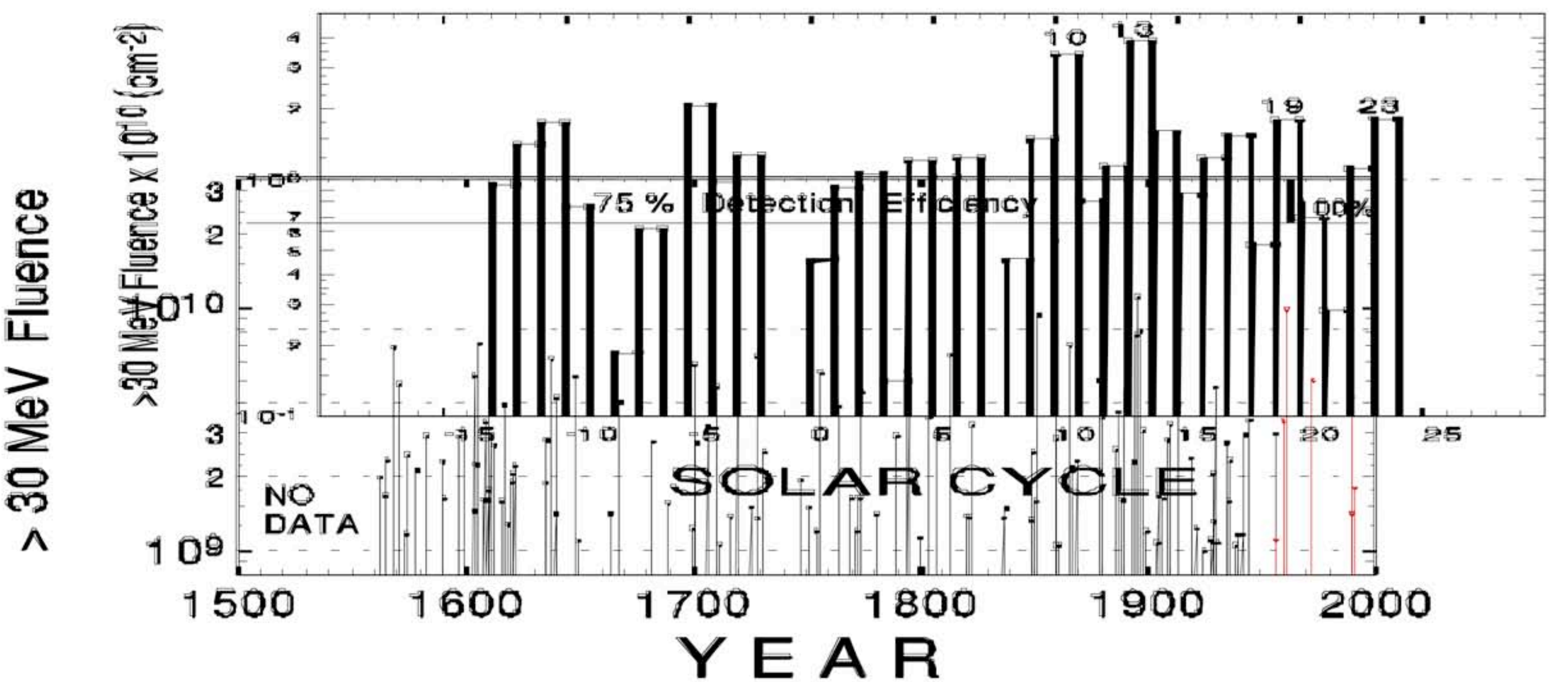


Top: Nitrate data from the 2004 Greenland core with annotated solar events. (High resolution)

Bottom: Nitrate deposition data from 1988 -1989 Antarctica ice cores. (1.5 cm resolution)

Paper 725, Kepko et al.

31 solar cycles between 1610 and 1954 (cycle -12 through cycle 18)



Cycle 10 was dominated by one major event (the Carrington event in 1859)
Cycle 13 had 7 major events contributing to the total fluence.
The total fluence for most cycles is within a factor of 2 of the maximum fluence per cycle measured by spacecraft since 1965

see also McCracken et al., JGR **106**(A10), 21’585–21’598, 2001 Paper 718, Shea et al.

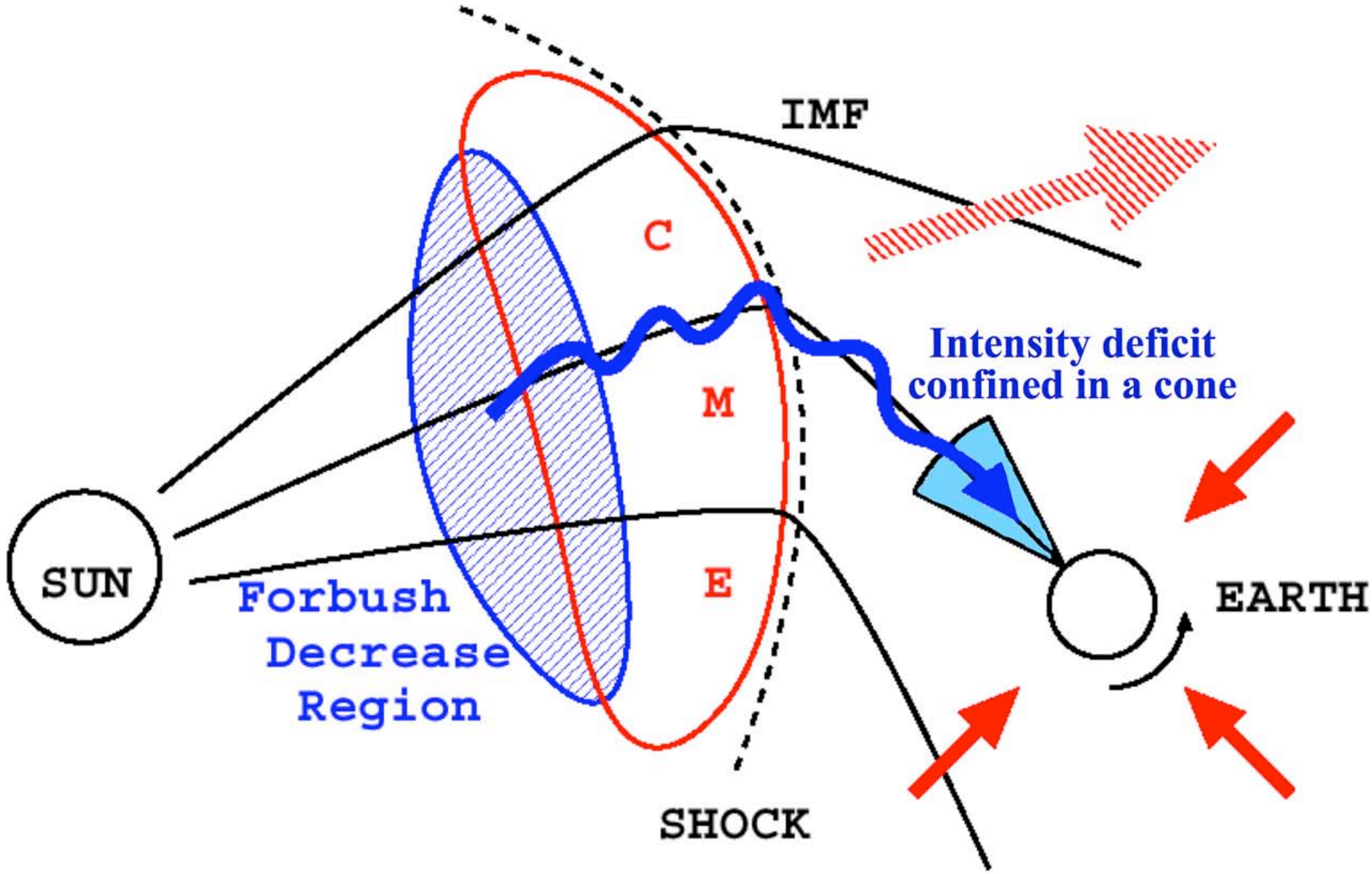
New Techniques, „Potential Highflyers“

- 296 - Muon diagnostics of the Earth's atmosphere, near-terrestrial space and heliosphere: first results and perspectives
  Timashkov et al.
- 364 - Interaction of GeV Protons with Circumsolar Dust Grains
  Kahler & Ragot
- 439 - Burst profile of lightning generated neutrons detected by Gulmarg Lead-free Neutron Monitor
  SHAH et al.

Muon Diagnostices

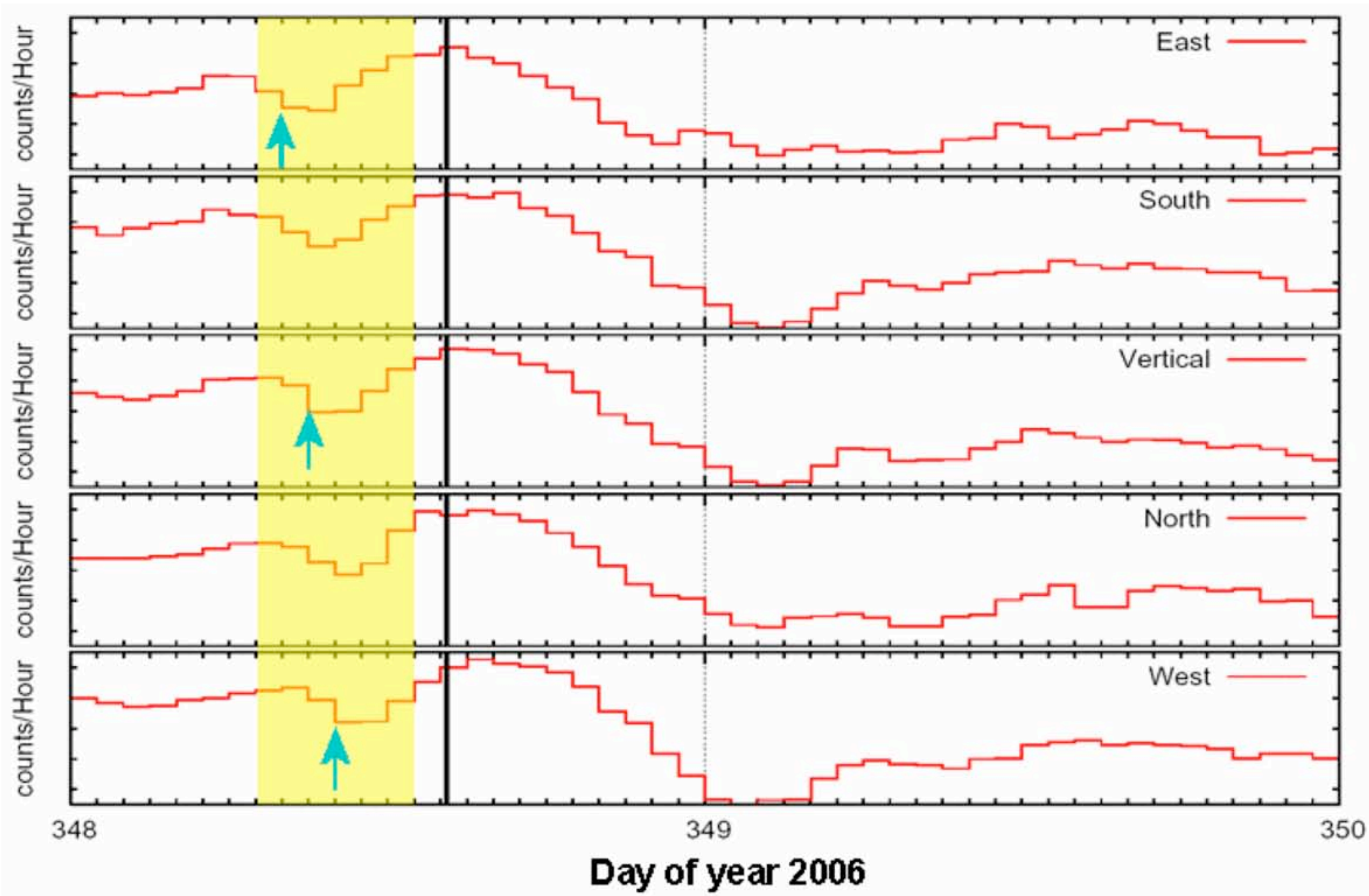
Loss-cone precursors

Nagashima et al. [1992], Ruffolo [1999]



Bieber, ICRC 2007 Workshop

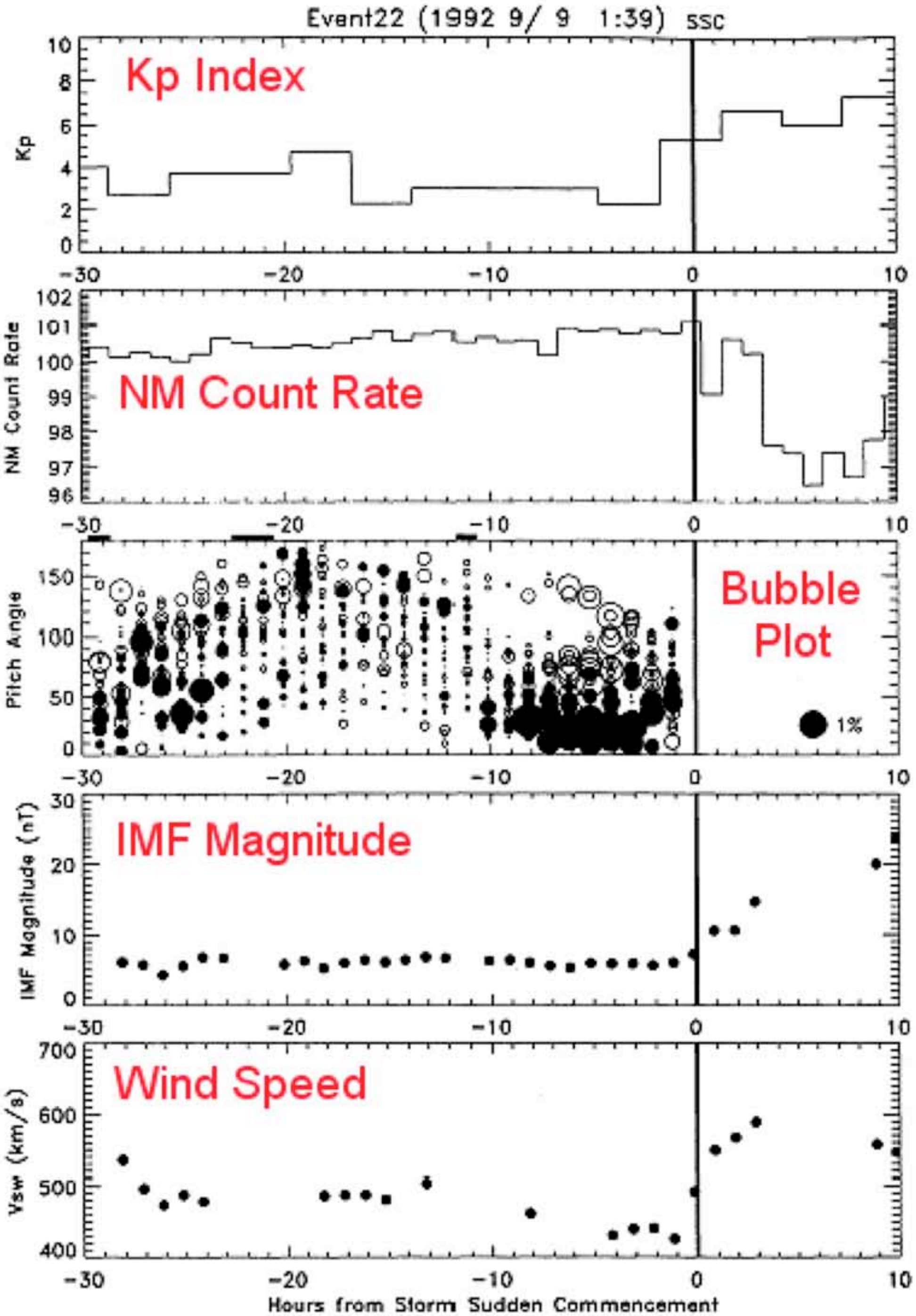
Loss Cones appear as a "Predecrease" when viewed by a single detector



- Event on Dec 14, 2006 observed by muon detector in São Martinho, Brazil
- As detector viewing direction rotates through loss cone, a predecrease is seen first from the East, then from Vertical, and finally from West

Bieber, ICRC 2007 Workshop

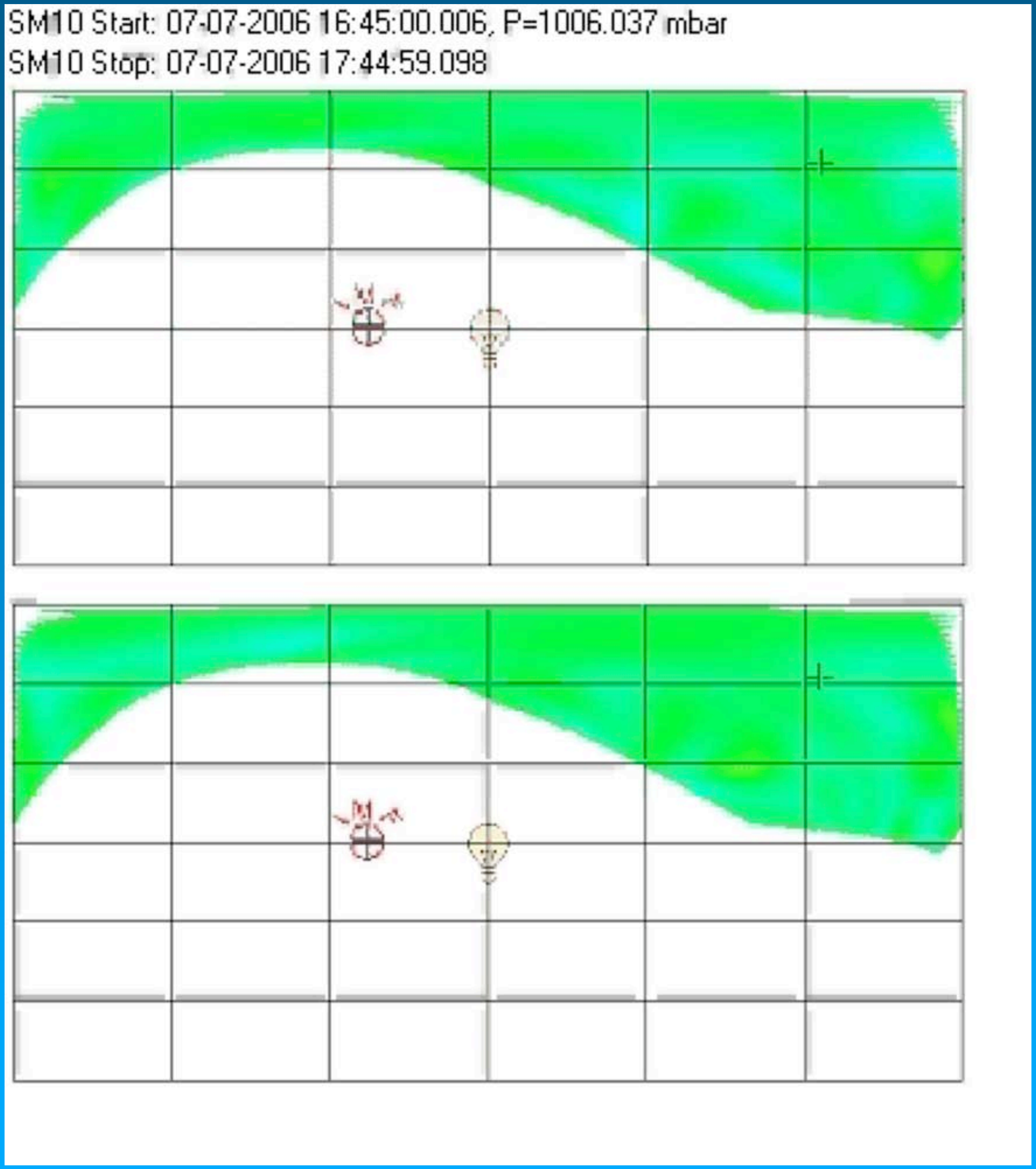
Loss Cones Can Be Seen in a "Bubble Plot" in Large Events



- In this bubble plot, each circle represents a directional channel in a muon telescope
- Circle is plotted at time of observation (abscissa) and pitch angle of asymptotic viewing direction (ordinate)
- Solid circles indicate a deficit intensity relative to omnidirectional average, and open circles indicate excess intensity; scale is indicated at left of plot
- Loss cone is evidenced by large solid circles concentrated near 0^{O} pitch angle
- Figure adapted from Munakata et al., *J. Geophys. Res.*, **105**, 27457-27468, 2000.

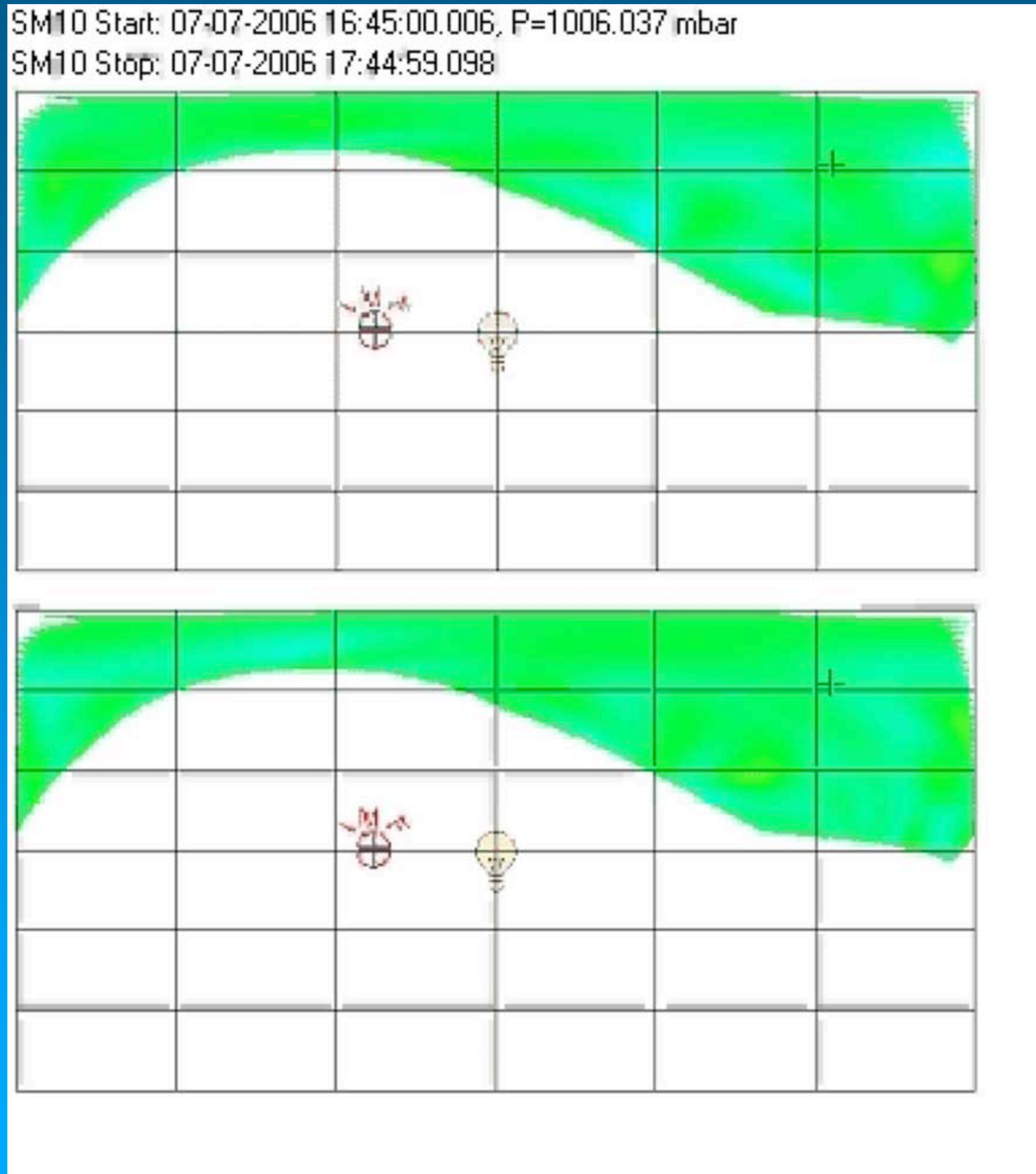
Bieber, ICRC 2007 Workshop

URAGAN muon hodoscope



Paper 298, Timashkov et al.

URAGAN muon hodoscope



Paper 298, Timashkov et al.

Take home messages

- New large GLE on December 13, 2006
- Ongoing discussion about two mechnisms for particle acceleration at the Sun (on the basis of the January 20, 2005 GLE)
- Cosmogenic Radionuclides (^{7}Be, ^{10}Be, ^{14}C)

  New type of Neutron Monitor with time range of up to 100’000 years
- Nitrate technique for GLE archive established
- New probing techniques for space weather applications: muon diagnostics