COSMOGENIC NUCLIDES (Cosmic Ray Produced Nuclides) past, present, and future

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Cosmogenic nuclides

- The research involves measurement of radioactive and stable nuclides produced in extraterrestrial and terrestrial materials by cosmic rays.
- The goal is to understand the history of both the target and the radiation (Cosmic Ray).
- Timescales range from 10^9 years to the present.

Cosmogenic Nuclides

Nuclide	Half-life (yr)	Major targets	Major production
^{54}Mn	0.855	Fe	SCR, GCR
^{22}Na	2.61	Mg, Si	SCR, GCR
^{60}Co	5.27	Co	N_{th}
^{14}C	5,730	O, N	GCR, (n,p)
^{59}Ni	7.6×10^{4}	Fe, Ni	N_{th}
^{41}Ca	1.04×10^{5}	Fe, Ca	GCR, N_{th}
^{81}Kr	2.3×10^{5}	Sr, Y, Zr	GCR
^{36}Cl	3.01×10^{5}	K, Ca, Fe, Cl	GCR, N_{th}
^{26}Al	7.05×10^{5}	Si, Al	SCR, GCR
^{10}Be	1.36×10^{6}	O, Mg, Si	GCR
^{53}Mn	3.7×10^{6}	Fe	SCR, GCR
^{129}I	1.57×10^{7}	Te, Ba, La	GCR, N_{th}
^{3}He	stable	O, Mg, Si, Fe	GCR
$^{21,22}Ne$	stable	Mg, Si	GCR
$^{36,38}Ar$	stable	Ca, Fe	GCR
^{150}Sm	stable	^{149}Sm	N_{th}
^{158}Gd	stable	^{157}Gd	N_{th}

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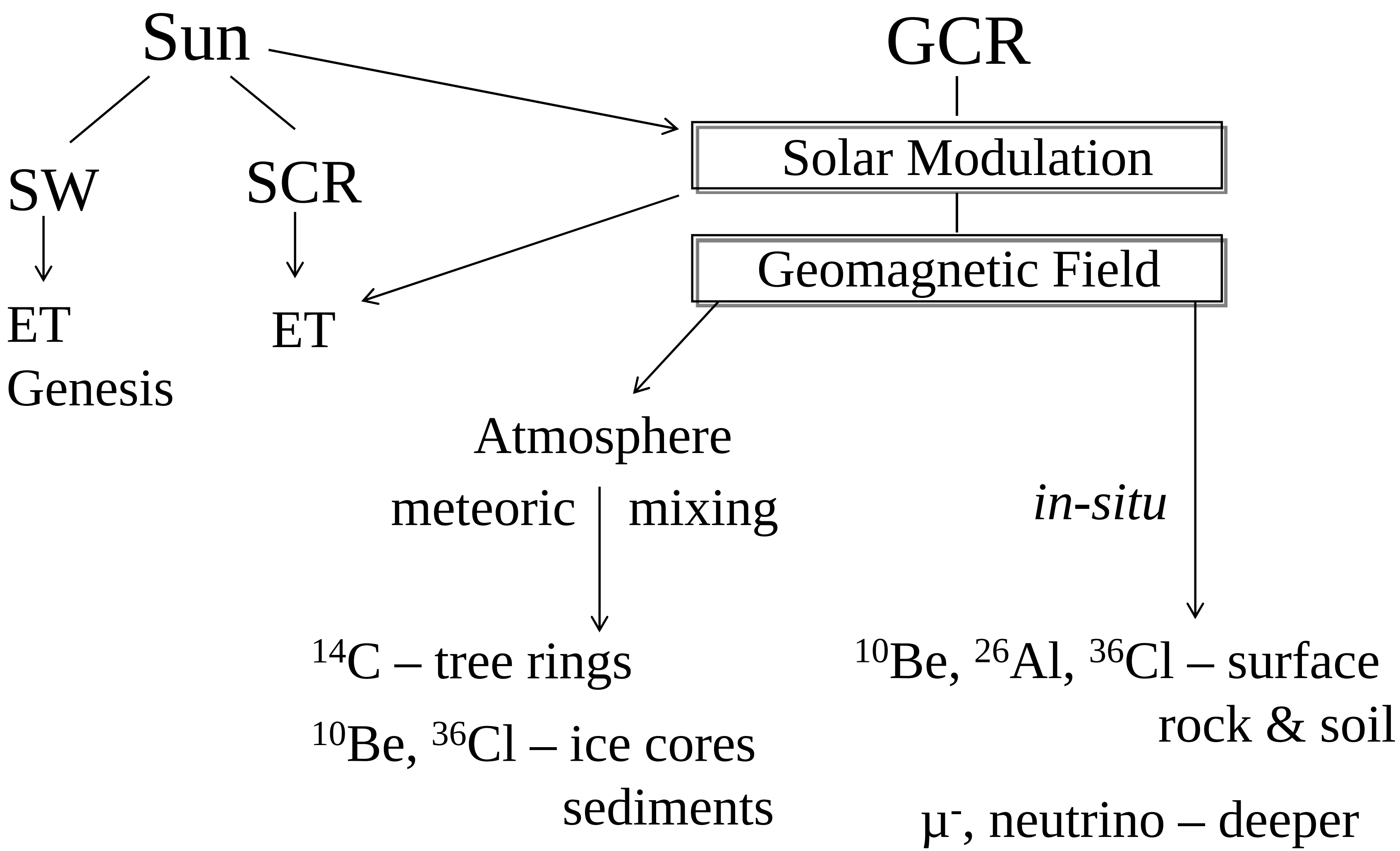
Cosmic Rays & Cosmogenic Nuclides



Cosmogenic Nuclides on the Earth

Helium and Hydrogen of Mass 3

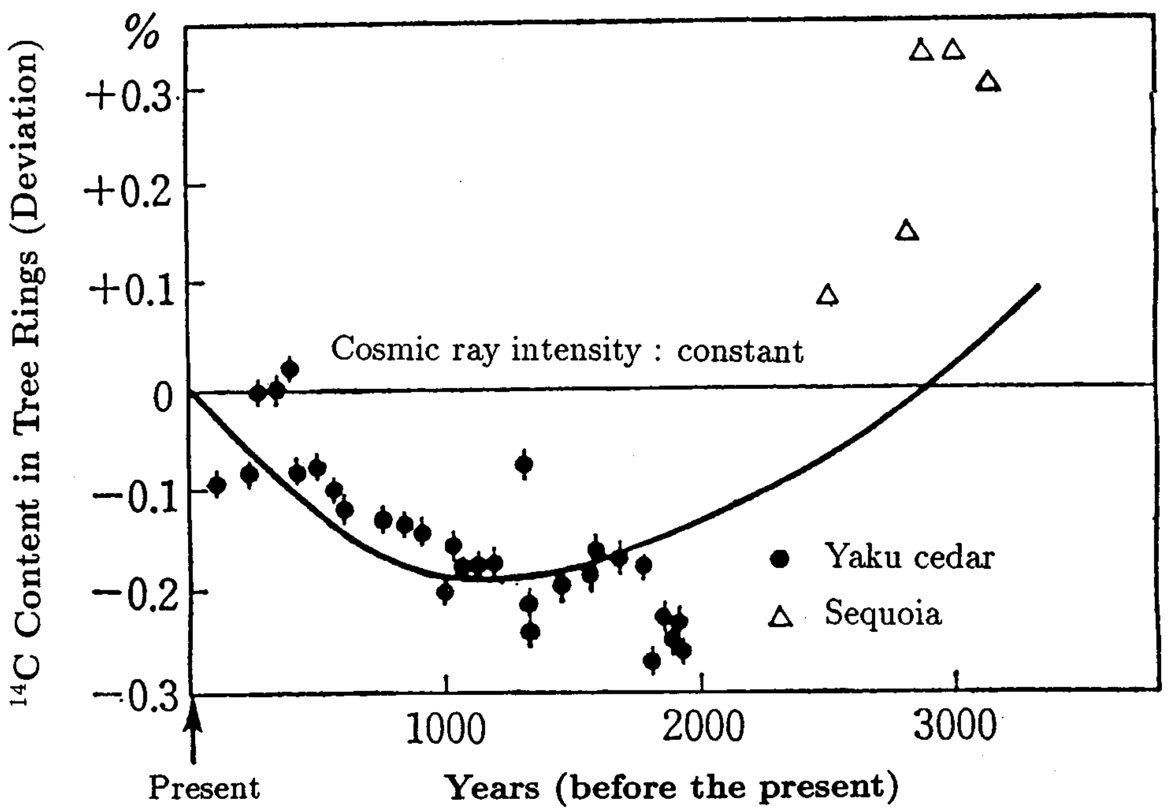
Luis W. Alvarez and Robert Cornog
(Phys. Rev. 1939)

Atmospheric Helium Three and Radiocarbon from Cosmic Radiation

W. F. Libby
(Phys. Rev. 1946)

Variation of ^{14}C content in the atmosphere during the past two thousand years

K. Kigoshi *et al.*
(Proc. 9th Int. Cosmic Ray Conf.,1965)



CHLORINE-36 IN NATURE

Raymond Davis, Jr. and Oliver A. Schaeffer

June 1955

JOURNAL OF GEOPHYSICAL RESEARCH VOL. 73, NO. 10, MAY 15, 1968

Search for Aluminum 26 Induced by Cosmic-Ray Muons in Terrestrial Rock

S. TANAKA, K. SAKAMOTO, J. TAKAGI, AND M. TSUCHIMOTO

Institute for Nuclear Study, University of Tokyo, Tanashi, Tokyo, Japan

Terrestrial Al^{26} produced by cosmic-ray muons has been sought in silicate rock. Aluminum was isolated and purified from tens of kilograms of chert obtained from an area with a low erosion rate. Al^{26} was counted with a low-level gamma-gamma coincidence spectrometer. The specific activity for the present surface rock has been measured to be (0.02 ± 0.12) dpm/10 kg SiO_2, and the specific activity for the rock at a depth of 24 meters of water equivalent, to be (0.00 ± 0.08) dpm/10 kg SiO_2. The Al^{26} activity in terrestrial rocks has been limited to 0.01 dpm/kg SiO_2.

Cosmogenic Nuclides in Meteorites

- "Investigation to detect any cosmic-ray radioelements (such as ^{14}C)" by C. A. Bauer (1947)

- ^{3}He by A. Paneth et al. (1952)
- ^{3}H by F. Begemann *et al*. (1957)
  E. Fireman and Schwarzer (1957)

New techniques

Helium and Hydrogen of Mass 3

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(Phys. Rev. 1939)

Atmospheric Helium Three and Radiocarbon from Cosmic Radiation

W. F. Libby
(Phys. Rev. 1946)

New techniques

AMS (accelerator mass spectrometry)

- detection of 10^5-10^6 atoms of radionuclides
- reduce sample size $<10^{-5}$
  - ~ kg meteorite vs. <100 μg micrometeorite
  - a few tons of ice vs. ~100 g of ice

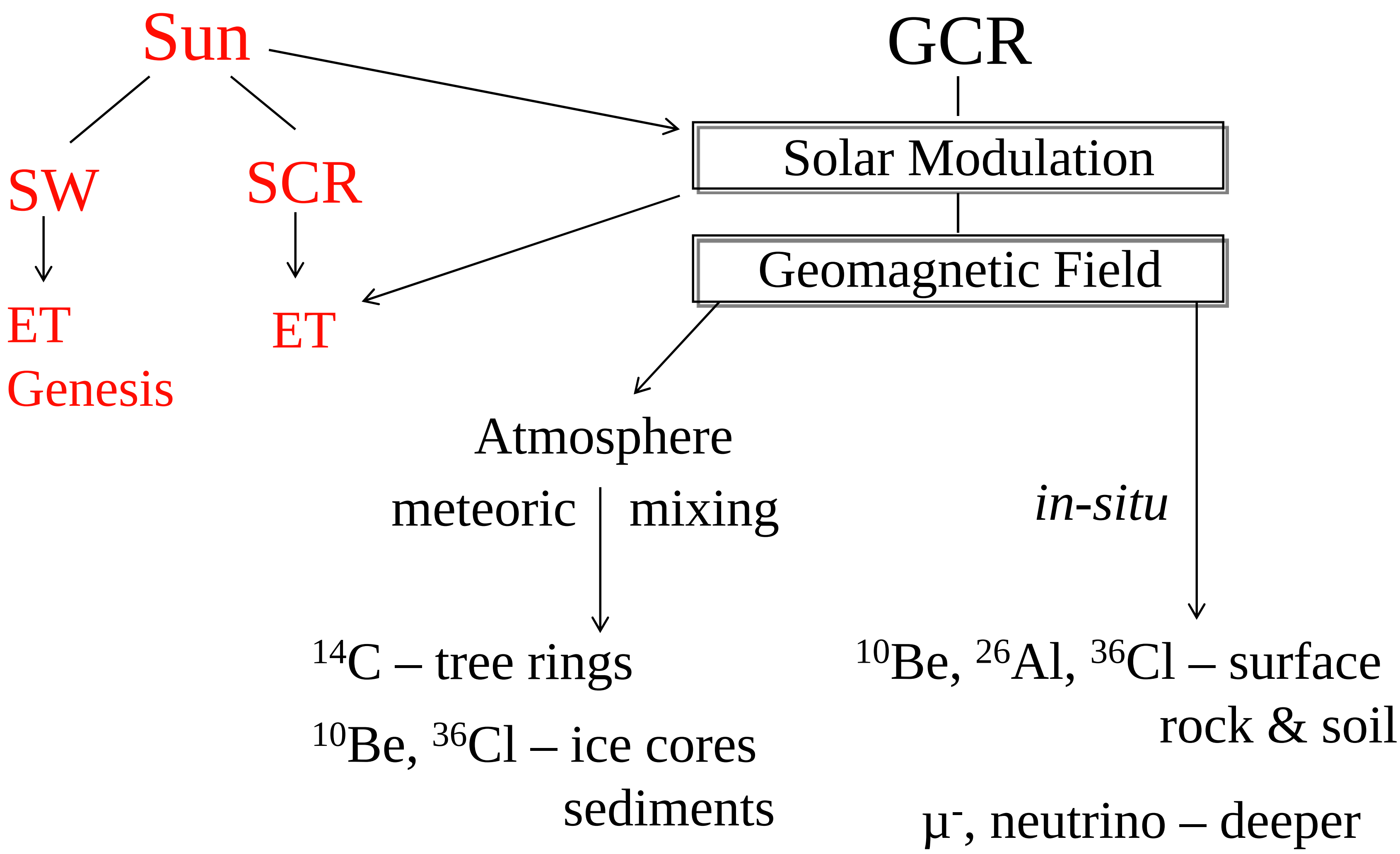
High sensitive noble gas mass spectrometry

- ~1,000 atoms of noble gas

New techniques

The high sensitive methods dramatically reduce sample size, increasing number of measurements, and expand applications of cosmogenic nuclide studies.

Cosmic Rays & Cosmogenic Nuclides



Cosmogenic nuclides in extraterrestrial materials

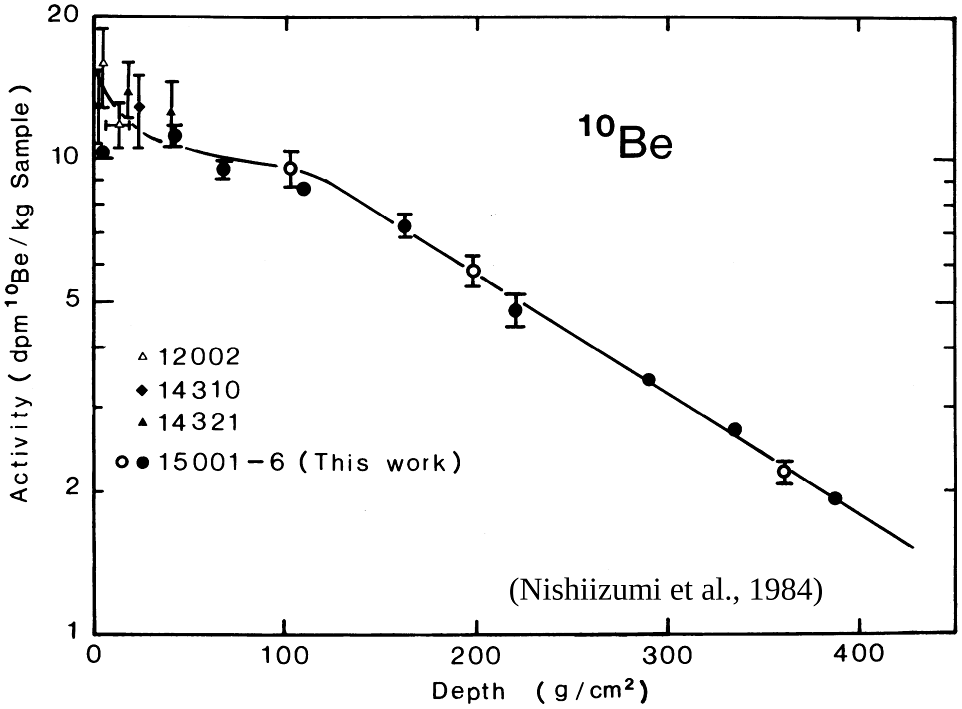
- Cosmic ray exposure ages and histories
- Ejection and orbital dynamics from the parent body to the earth
- Terrestrial ages
- GCR and SCR histories

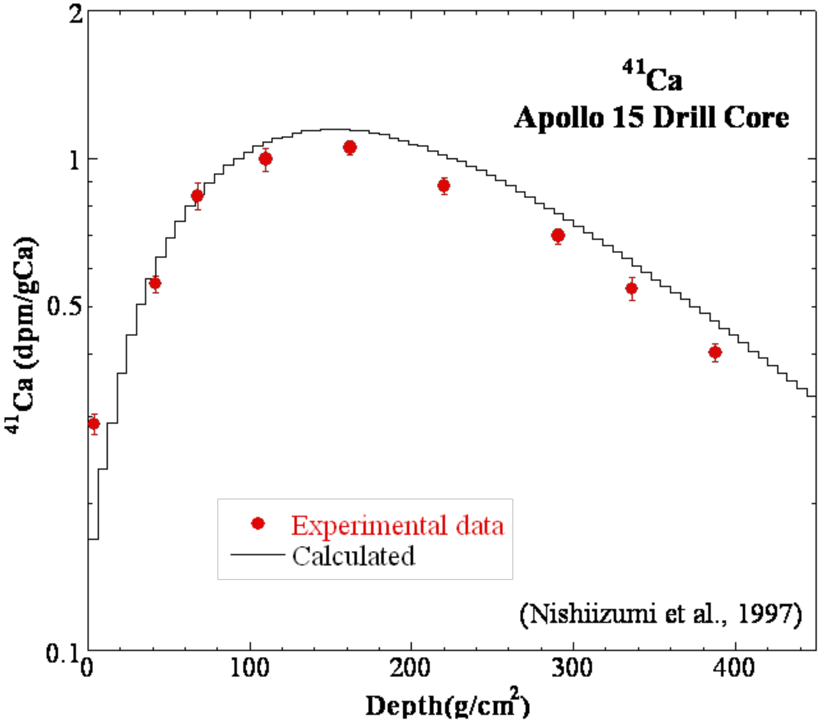
Production Rate of Cosmogenic Nuclide

$$P_j(E,x) = \Sigma_i N_i \Sigma_k \int_0^\infty \sigma_{ijk}(E_k) \cdot J_k(E_k, x) dE$$

Production rate
Cross section (excitation function)
Particle flux

Cosmogenic Nuclide Production Profiles in Apollo 15 Drill Core






64455,0
0 1 2 3 4
B1

Period	Data	Sample	Reference	R_0 MV	>10 MeV	>30 MeV	>60 MeV
1996-2006			Reedy, 2006, updated	64	278	61	10
1986-1996			Reedy, 1998	≈65	≈152	≈31	--
1976-1986			Goswami et al., 1988	40	63	5	~1
1965-1975			Reedy, 1977	90	92	30	8
1954-1964		12002	Reedy, 1977	100	~227	~82	~35
1954-2006			Average of above	≈80	≈150	≈42	≈12
~10 kyr	^{14}C	68815	Jull et al., 1998	113	≈103	42	17
~0.2 Myr	^{41}Ca	74275	Fink et al., 1998	80	~198	≈56	≈16
~0.3 Myr	^{81}Kr	68815	Reedy and Marti, 1991	~80	~160	~48	~15
~0.5 Myr	^{36}Cl	64455	Nishiizumi et al., 2007	70	196	46	11
~1 Myr	^{26}Al	68815	Kohl et al., 1978	100	70	25	9
~1 Myr	*	68815	Nishiizumi et al., 1988	70	150	35	8
~1 Myr	*	Several	Michel et al., 1996	125	55	24	11
~1 Myr	*	74275	Fink et al., 1998	100	89	32	12
~1 Myr	*	64455	Nishiizumi et al., 2007	85	80	24	7
~2 Myr	^{21}Ne	68815	Rao et al., 1994	85	68	21	6
~5 Myr	^{53}Mn	68815	Kohl et al., 1978	100	70	25	9

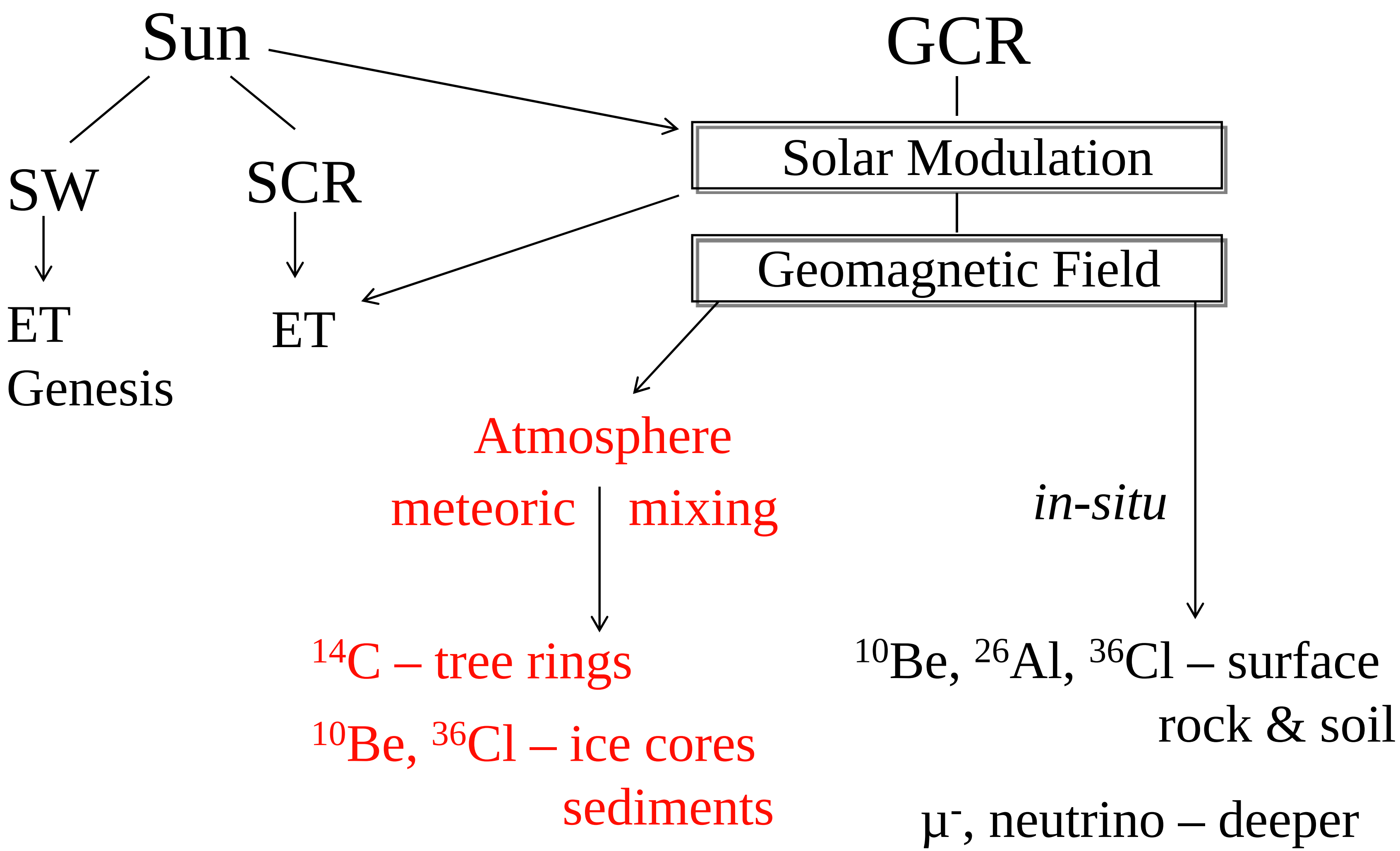
$$\frac{dJ}{dR} = k \cdot e^{-R/R_0}$$

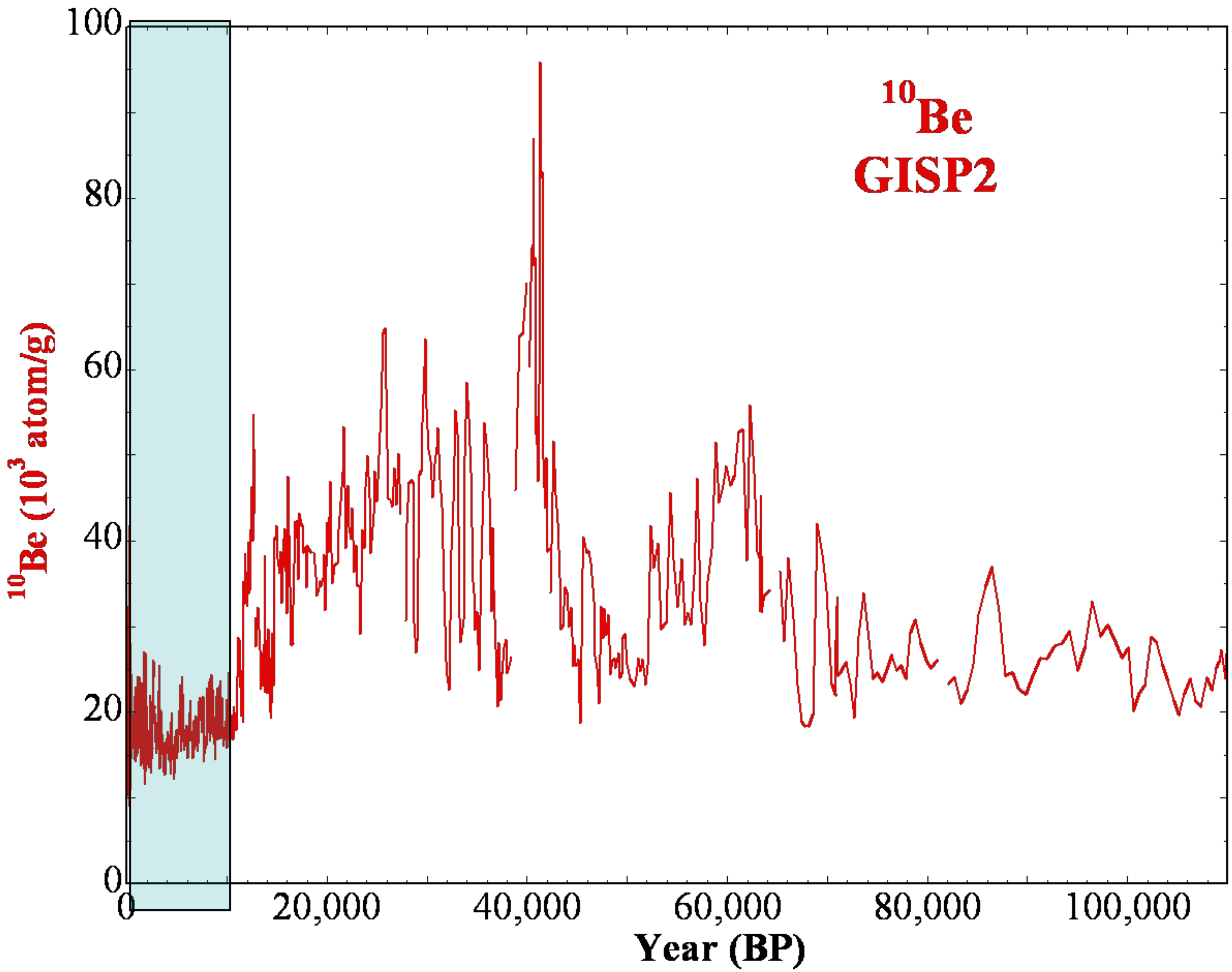
Present and future

- Increasing number of meteorites from Antarctica and hot desert.
  - ~ 2,000 vs. over 40,000 meteorites
  - *e.g.*, Martian and lunar meteorites
- Small samples
  - Micrometeorites, IDP, sample return (Hayabusa)

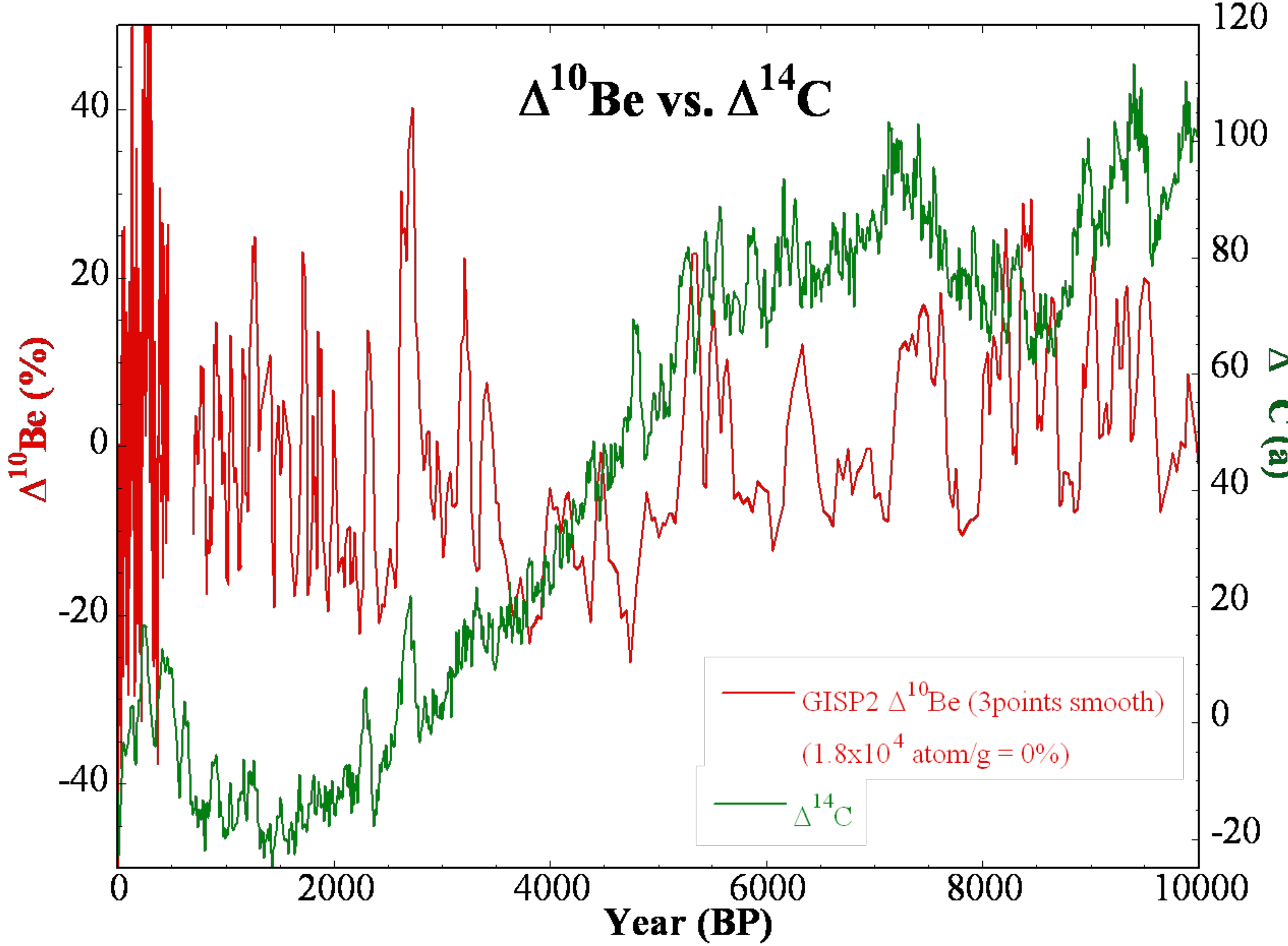
High sensitive and high throughput AMS and mass spectrometer.

Cosmic Rays & Cosmogenic Nuclides





(Nishiizumi *et al.*, unpublished)



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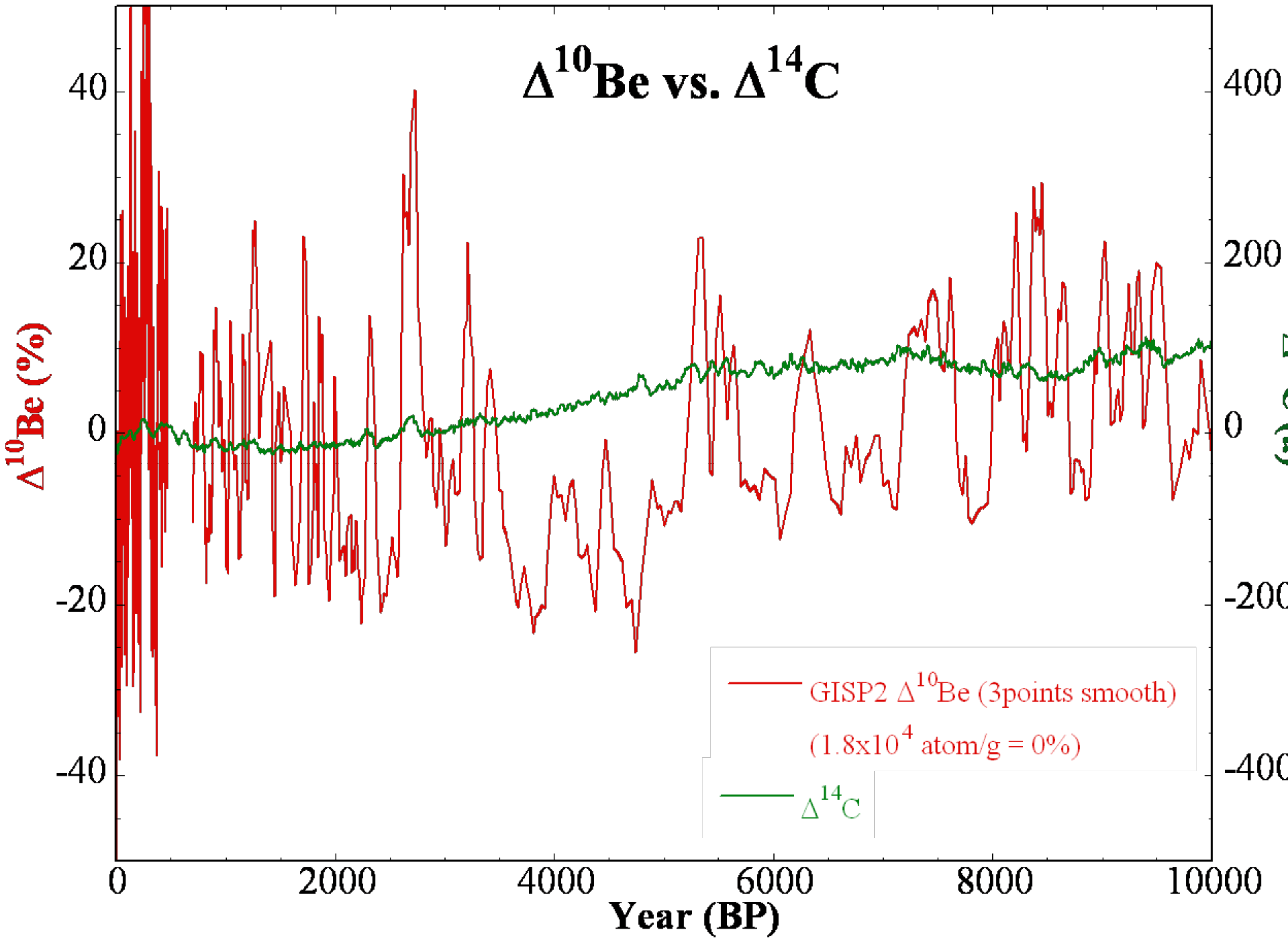

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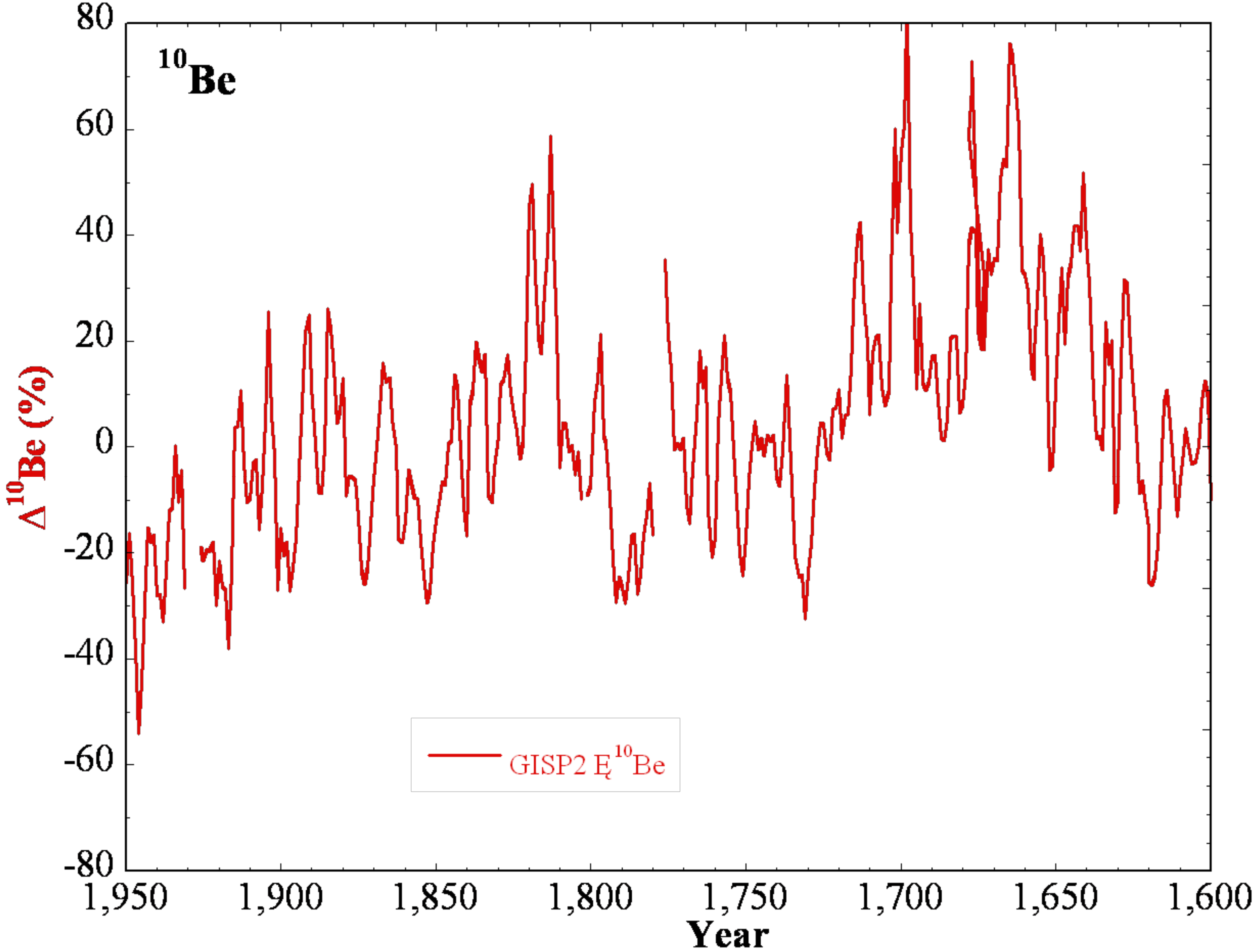

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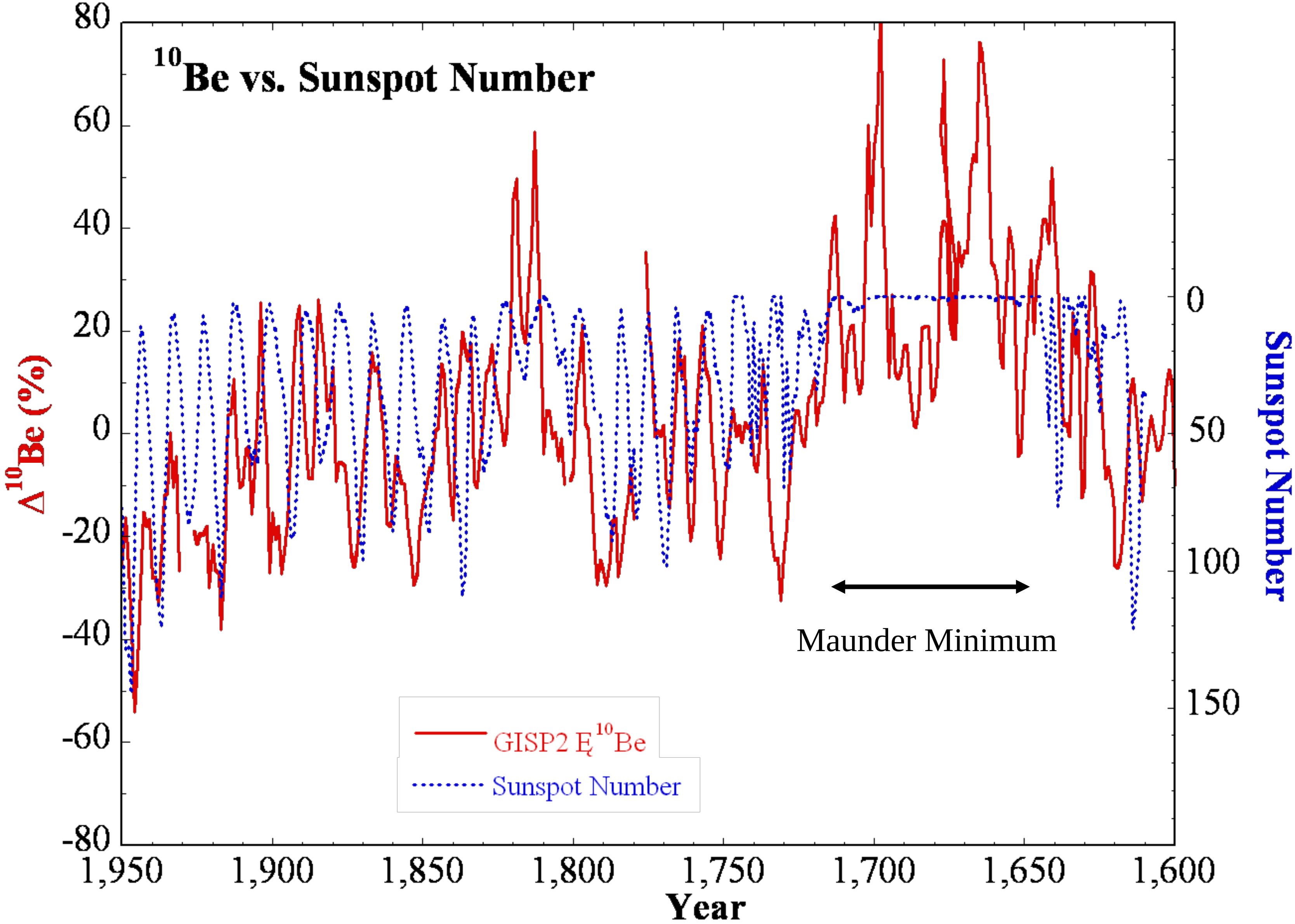

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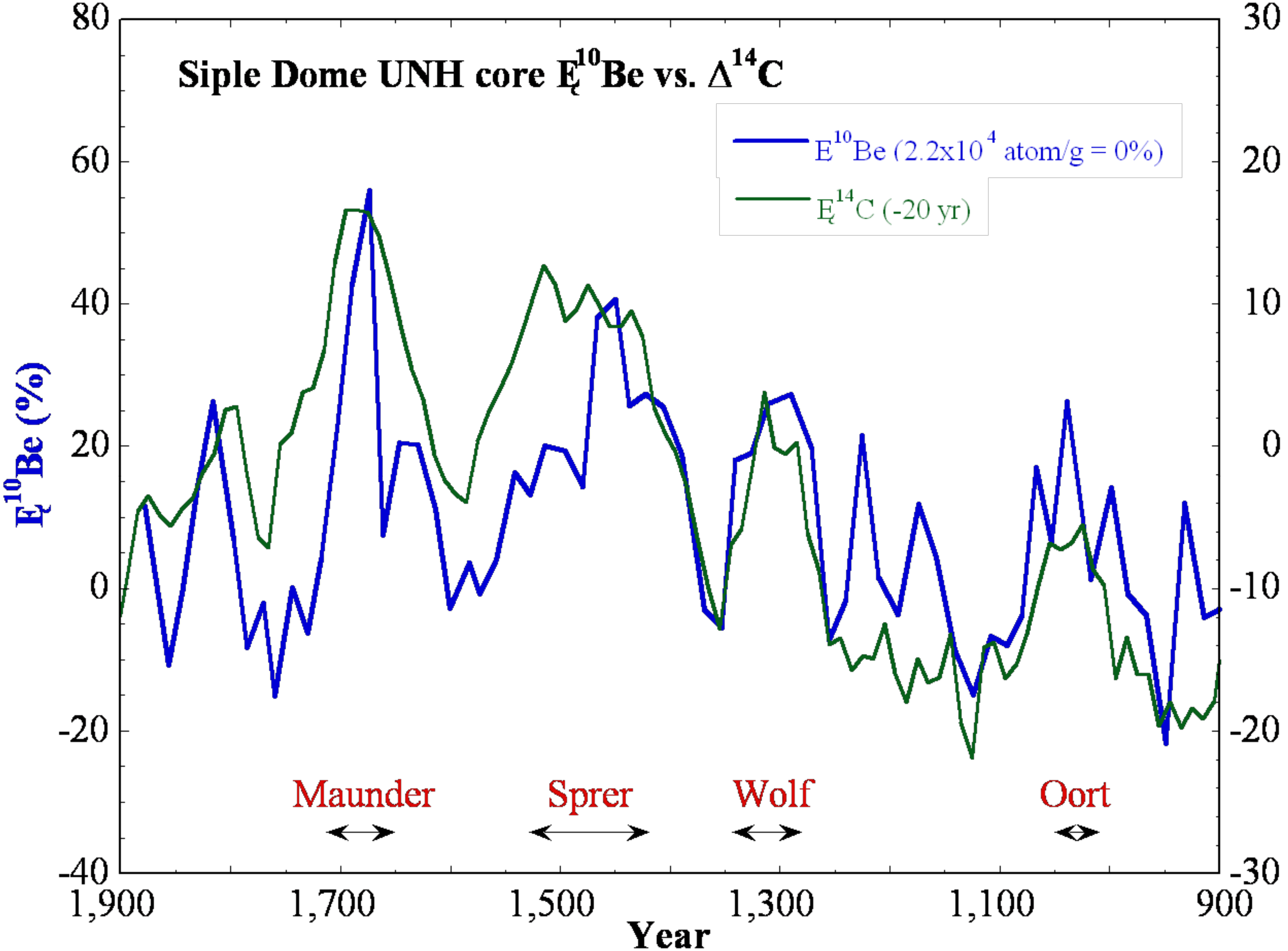


(Nishiizumi *et al.*, unpublished)

Present and future

Old and new deep ice cores

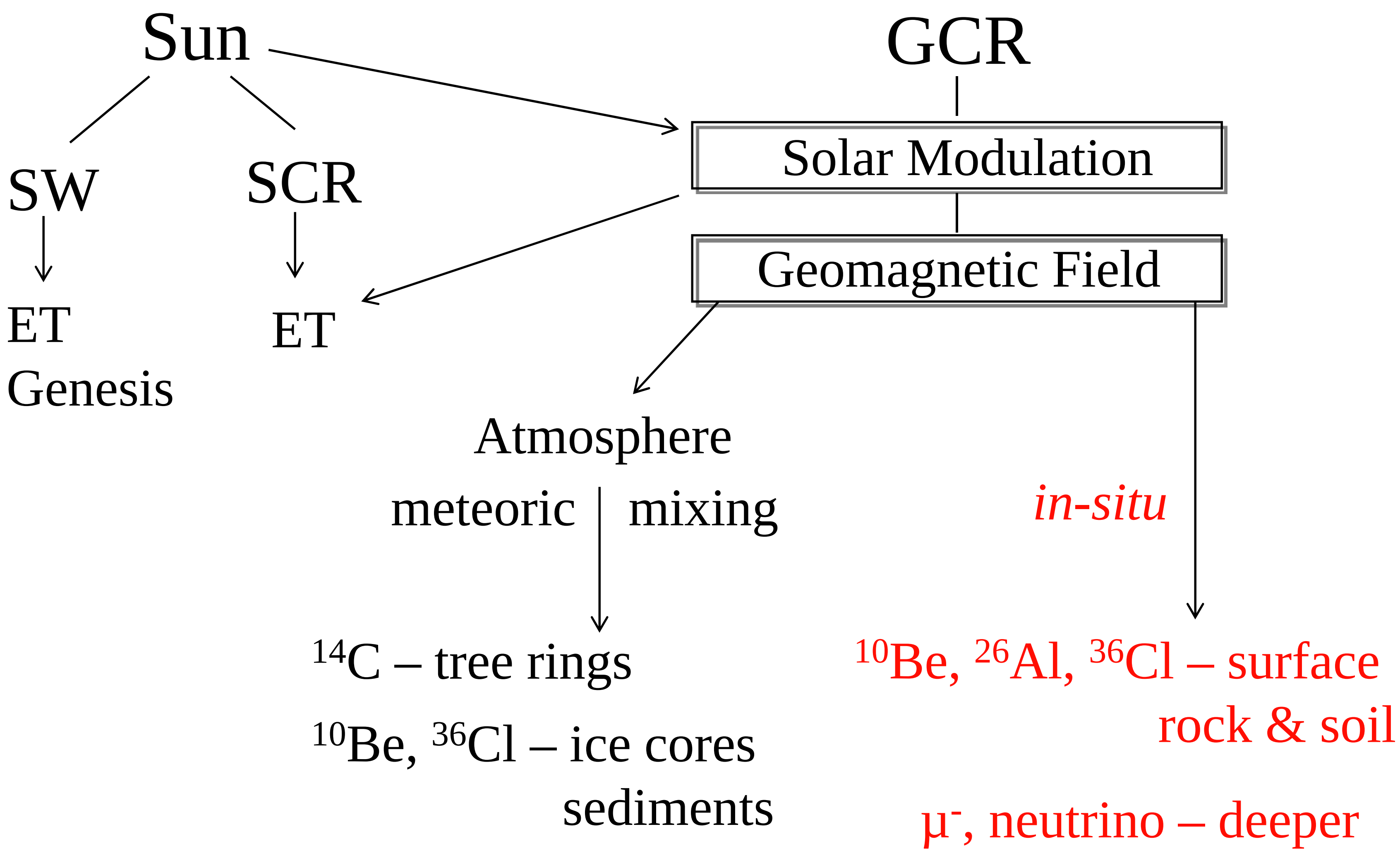
GISP2, GRIP, Vostok, Dome C

Dome Fuji, EPICA, North-GRIP, WAIS Divide

A few thousands cosmogenic radionuclide measurements

High throughput AMS

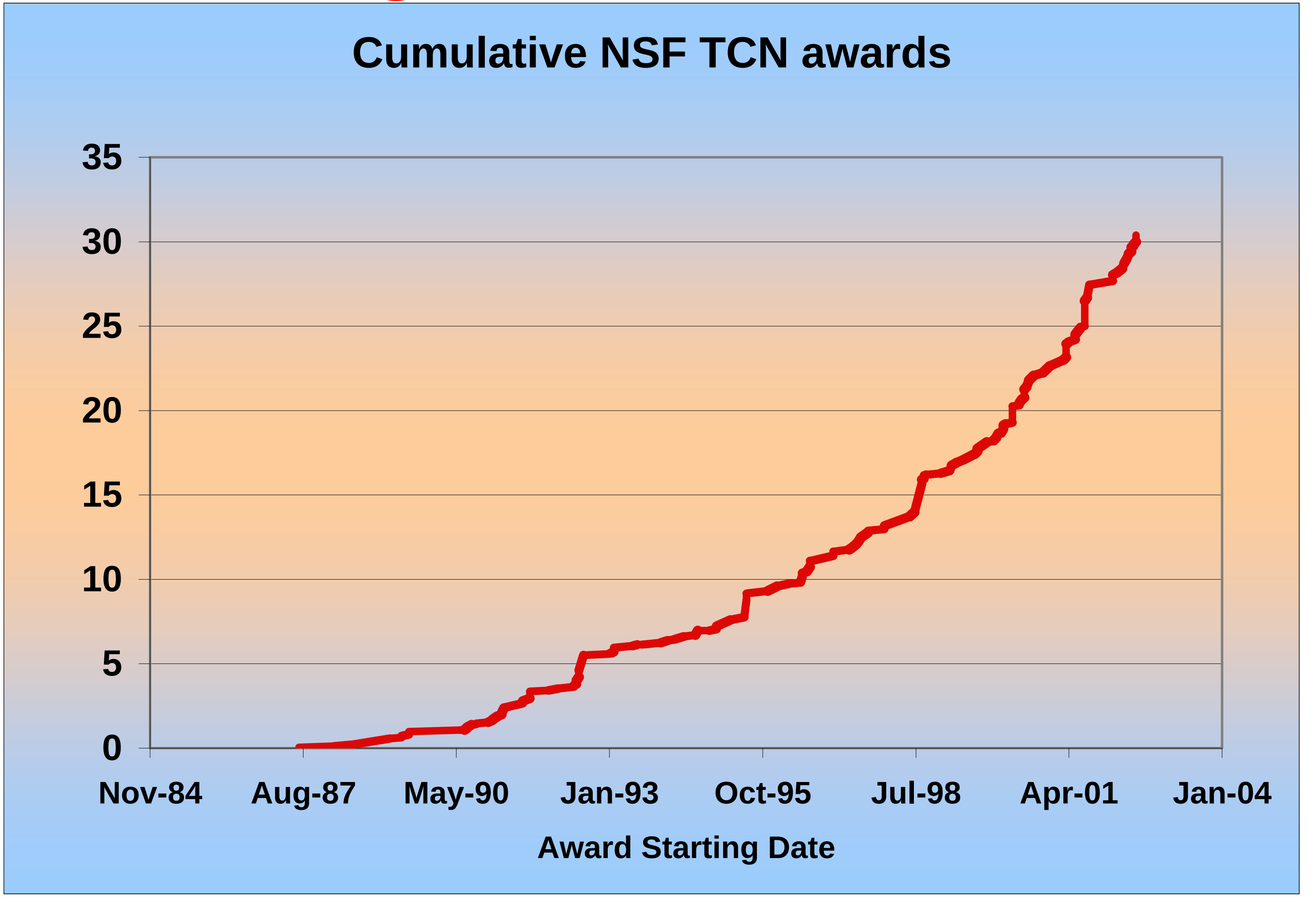
Cosmic Rays & Cosmogenic Nuclides



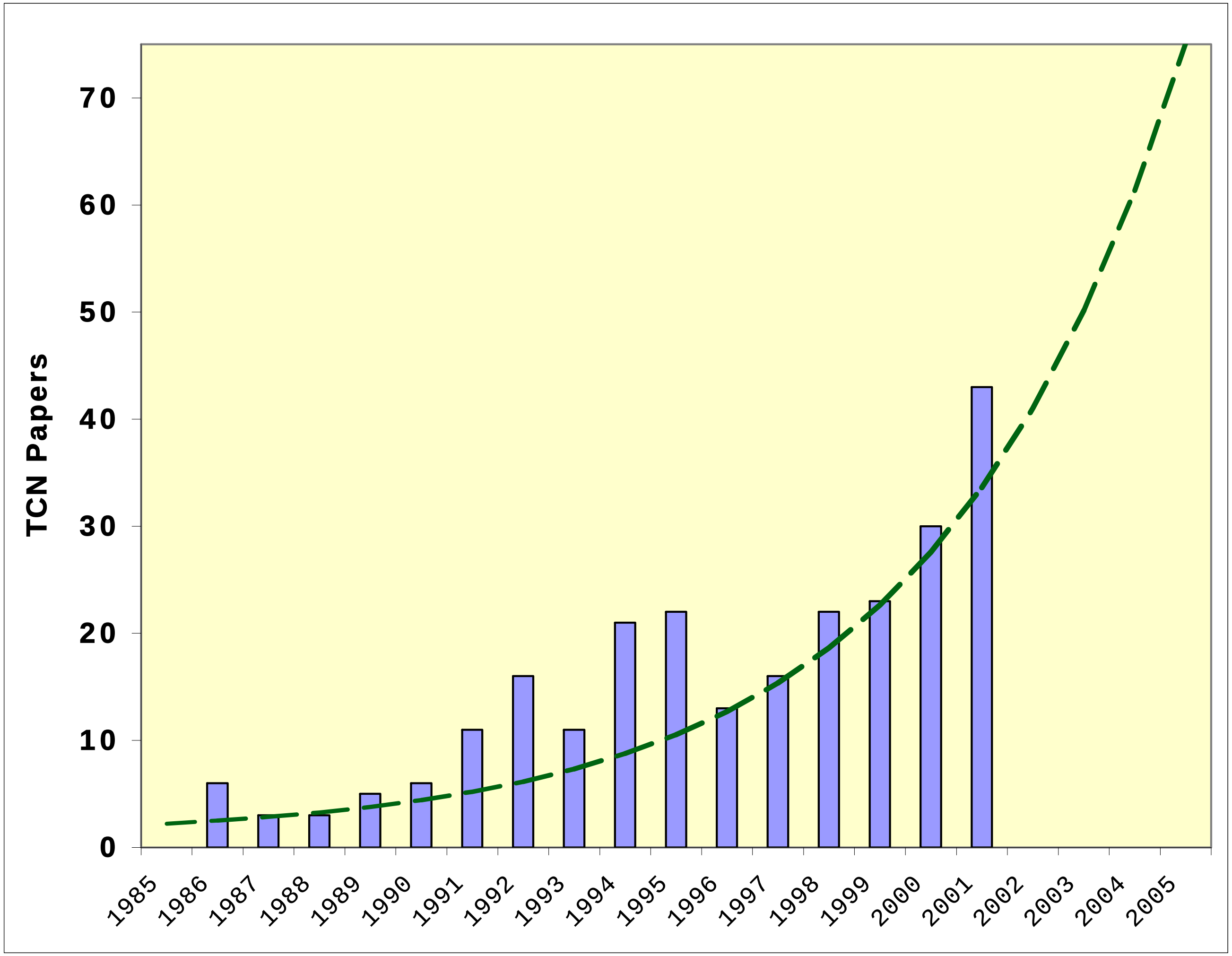
In-situ Produced Cosmogenic Nuclides on the Earth

- Dating landform
  - Glaciation - moraines and bedrocks
  - Lava flows
  - Bedrock erosion
  - Landslides/faults
  - River incision
  - Impact events
- Bedrock slopes and soil production
- Burial dating
- Aeolian dust - sand dunes

NSF Investment in Terrestrial Cosmogenic Nuclide Research



Rapid Increase in Applications and Publications



Present and future

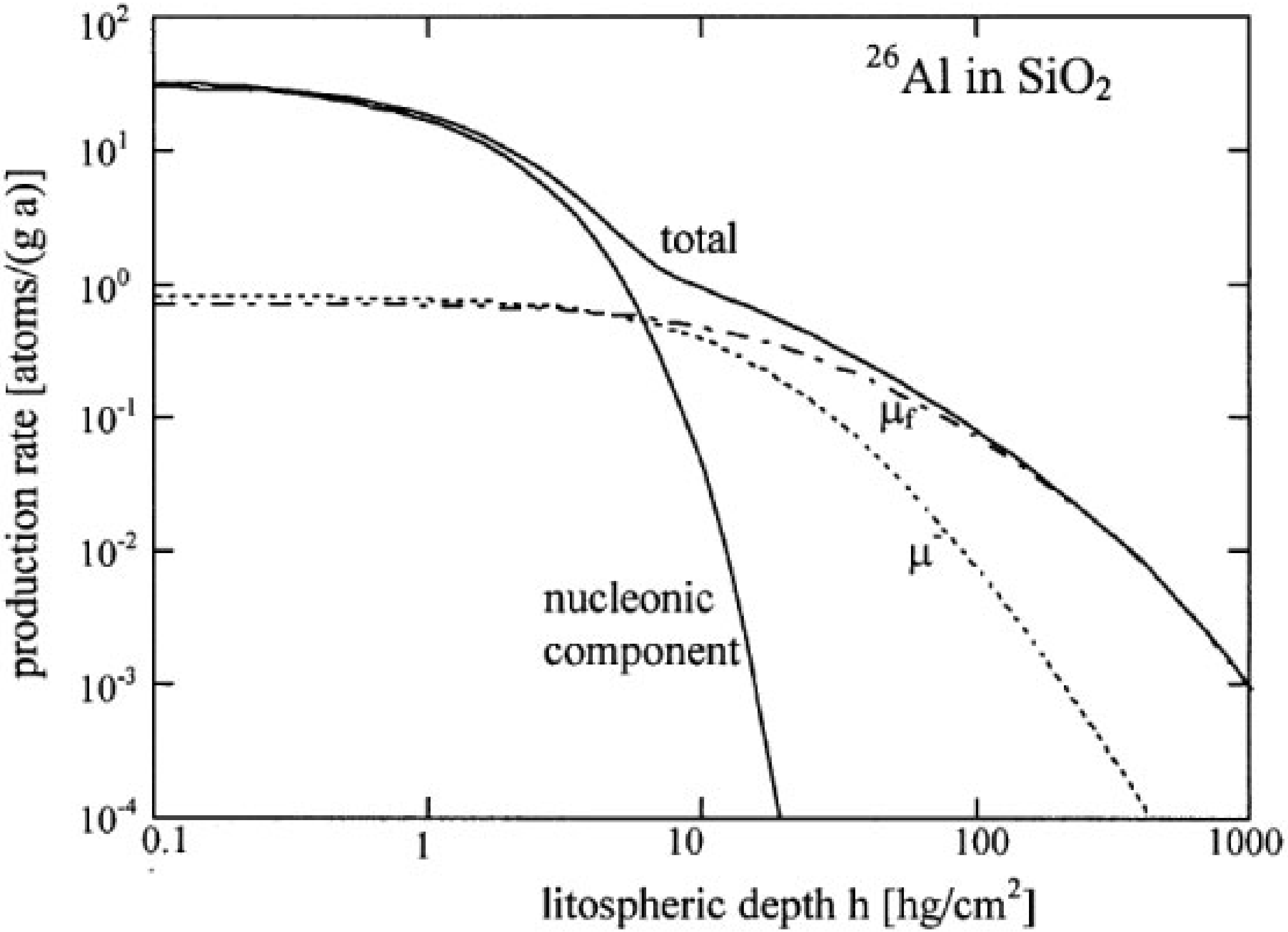
Increasing terrestrial applications using cosmogenic nuclides

Good production rate: Cronus-Earth, Cronus-Europe

High sensitive and high throughput AMS

Measurements of high energy neutron cross sections

Long-term cosmic ray intensity on the earth



(Heisinger *et al.*, 2002)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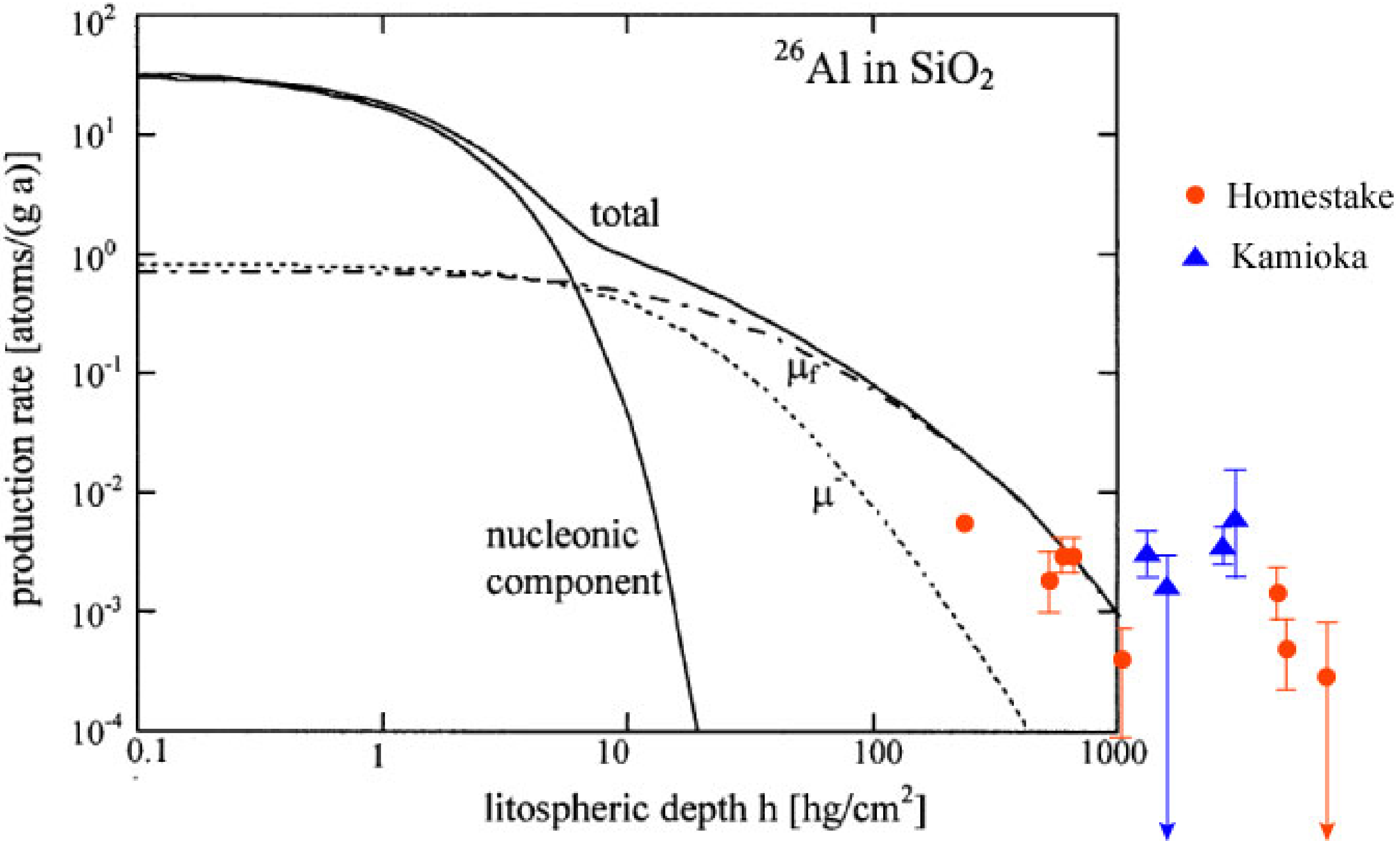

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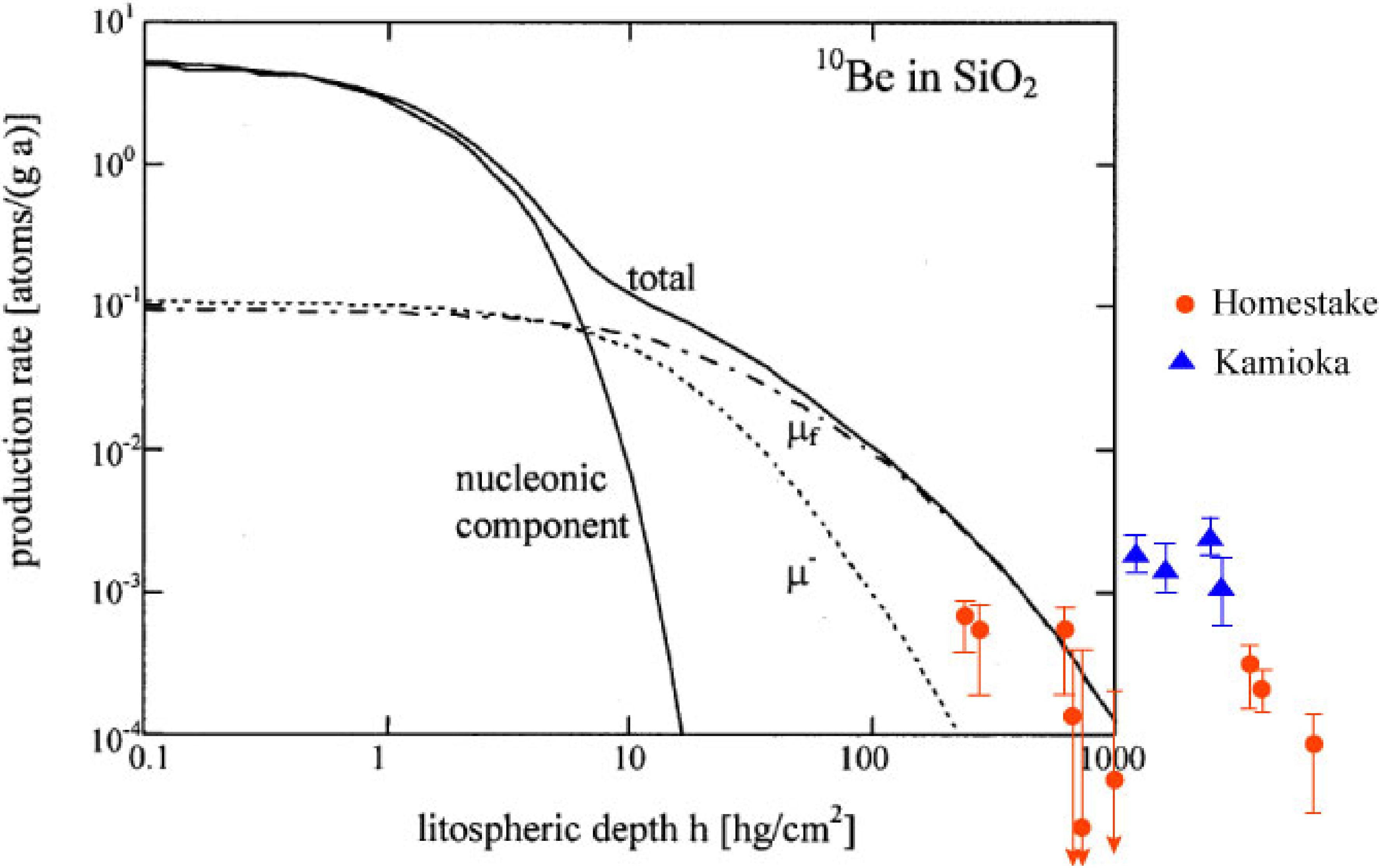
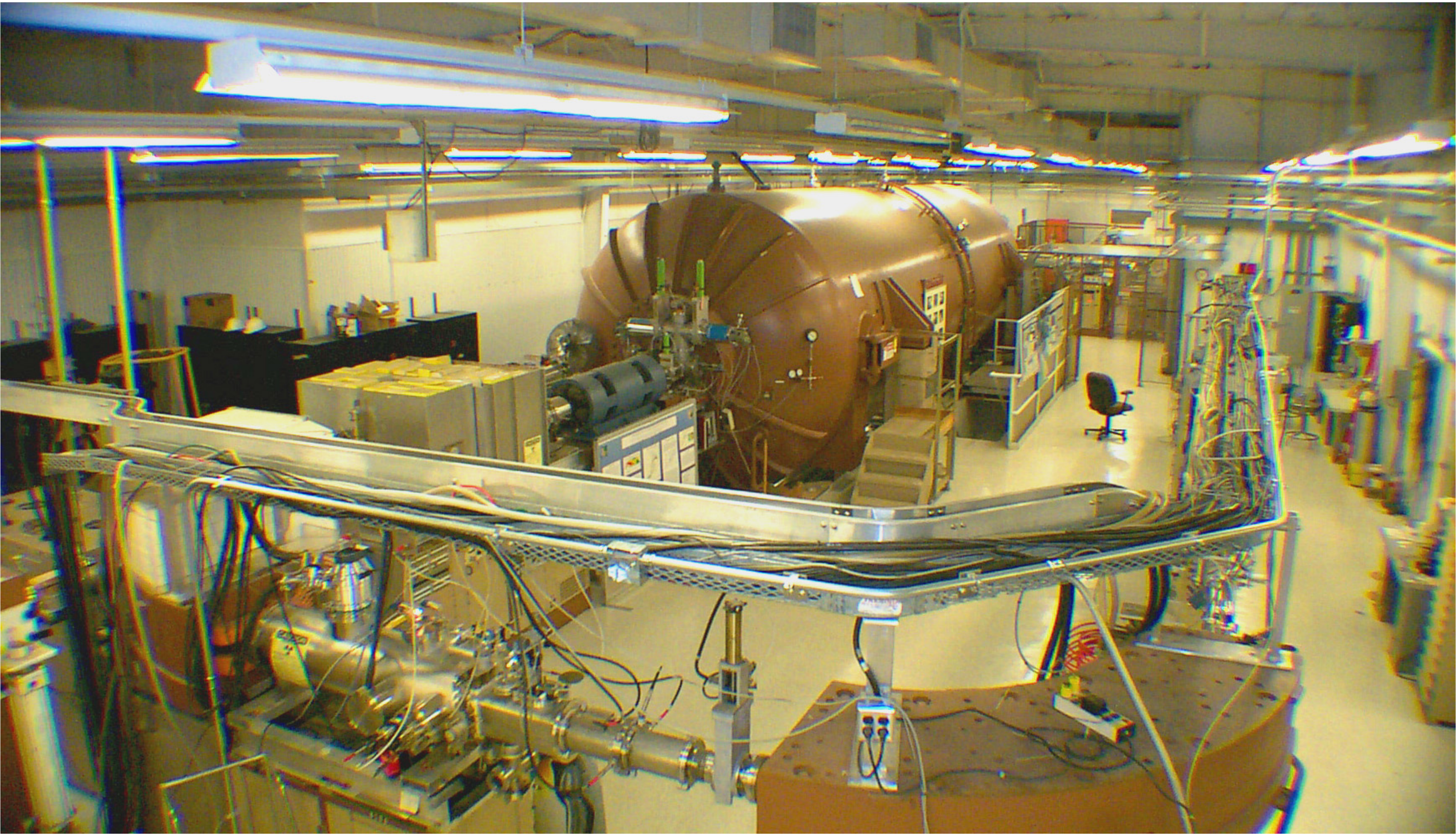


(Nishiizumi *et al.*, unpublished)

Cosmogenic Nuclides on Planetary Surface

- Sample return
- *In-situ* measurements



In-situ Measurements on Planetary Surface

- Cosmogenic radionuclides
  - Miniature AMS
- Cosmogenic stable nuclides
  - Miniature noble gas mass spectrometer

Future

- Continue expanding applications, especially terrestrial cosmogenic nuclide studies.
- Measurements of smaller samples-ET

We need

- Short-long term cosmic ray intensity changes
  - Geomagnetic field - terrestrial application
- High sensitive and high precision AMS
- High energy neutron cross sections
- Miniature AMS