Misura di isotopi cosmogenici in meteoriti

e variazioni dell'attività del Sole

Cosmogeophysics group:

C. Taricco, *P. Colombetti*, *S. Rubinetti*, *D. Barghini (Dipartimento di Fisica, Università di Torino)*

S. Mancuso, D. Gardiol, M. Di Martino (Osservatorio Astrofisico di Torino, INAF)

PRISMA – Day

16 Maggio 2017 - Firenze

Research topics

Measurement of meteorites:

γ-activity of cosmogenic radioisotopes

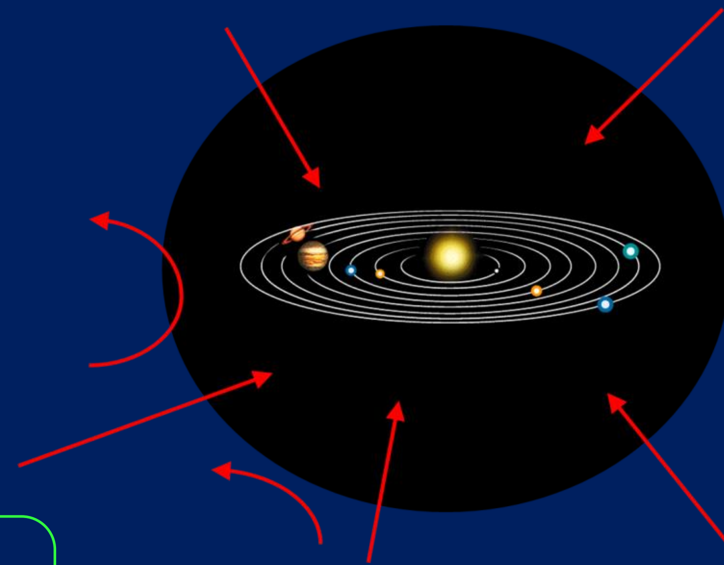
This measurement is useful to estimate the depth inside the meteoroid

Moreover, cosmogenic radioisotope activities can give important information about cosmic ray flux and their modulation in the heliosphere

Collaborations and agreements

- **OATo-INAF, Italy**
- **LNGS – INFN, Italy**
- **Physical Research Laboratory, Ahmedabad, India**
- **University of Copenhagen, Denmark**
- **University of Oulu, Finland**
- **University of Ferrara, Italy**

Cosmogenic radioisotopes



Galactic cosmic rays impact on target nuclei in meteoroids and on atmospheric particles

production of cosmogenic radioisotopes in meteorites and terrestrial archives

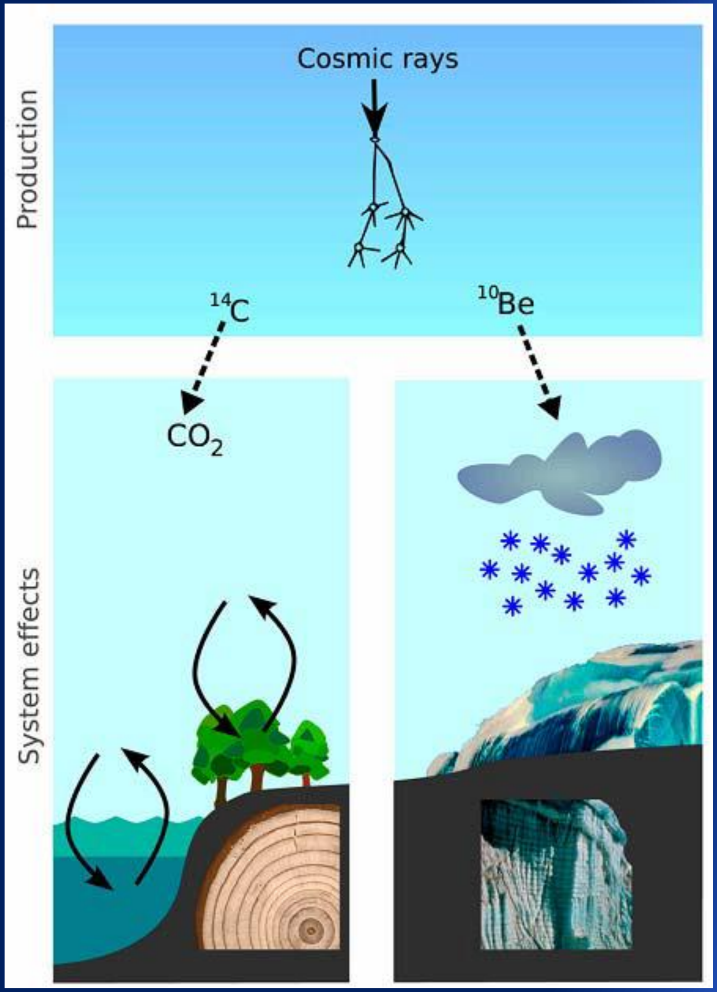
High solar activity

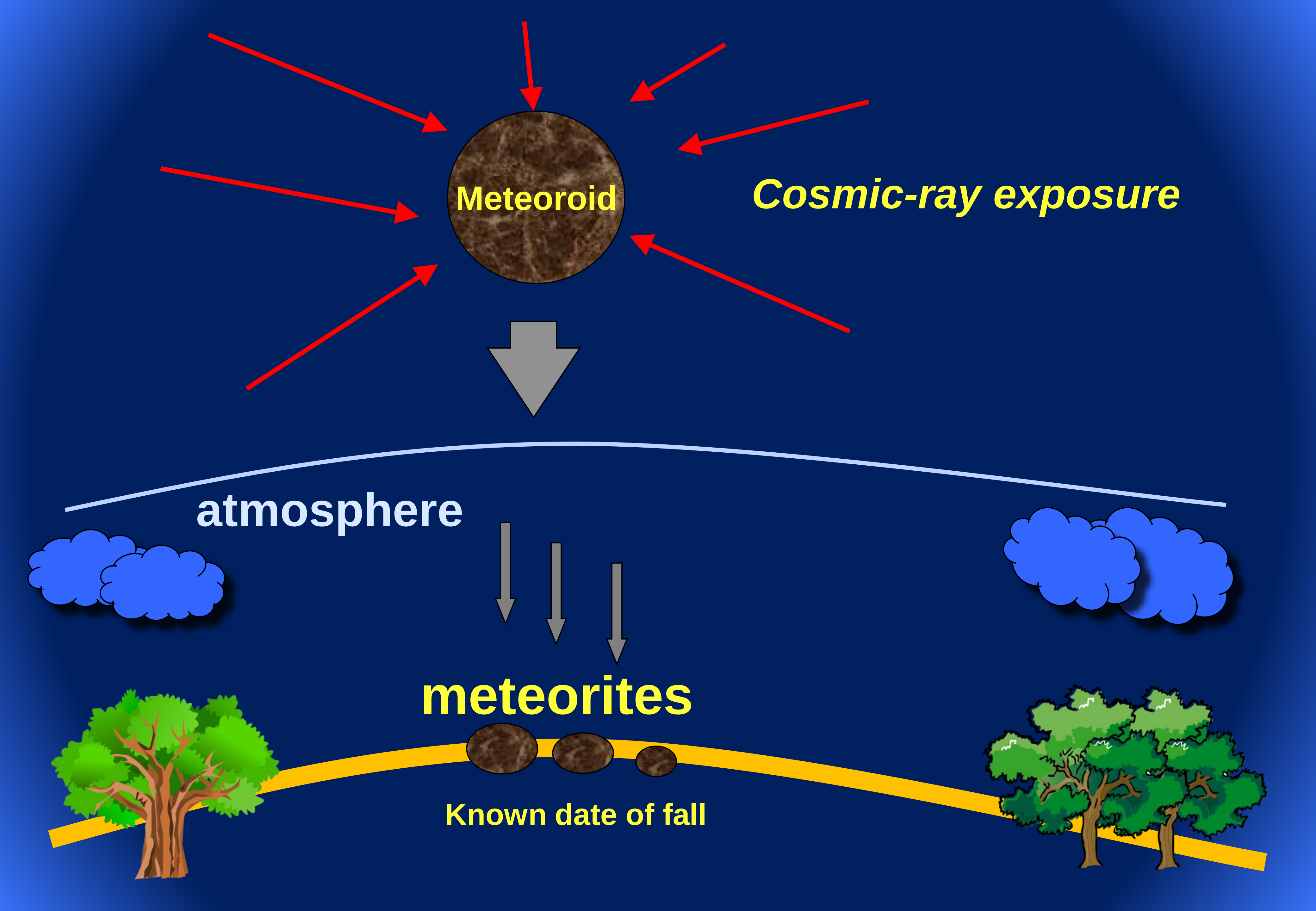
Low GCR flux intensity

Low production of cosmogenic radioisotopes

Solar activity in the past centuries is usually estimated by measuring records of cosmogenic radioisotopes ^{14}C and ^{10}Be produced by GCR in the Earth's atmosphere and deposited in terrestrial archives (tree rings and ice cores respectively)

BUT these reconstructions based on ^{10}Be and ^{14}C suffer from the influence of several terrestrial processes




Meteoroid
Cosmic-ray exposure
atmosphere
meteorites
Known date of fall

The activity of a radioisotope depends on the CR flux in space roughly over a mean life of the isotope before the meteorite falls on the Earth when the production ceases

By measuring activity in meteorites wich fell through the ages, we can evaluate the variability of the CR flux

Different $T_{1/2}$ allow to study CR variations on different time scales

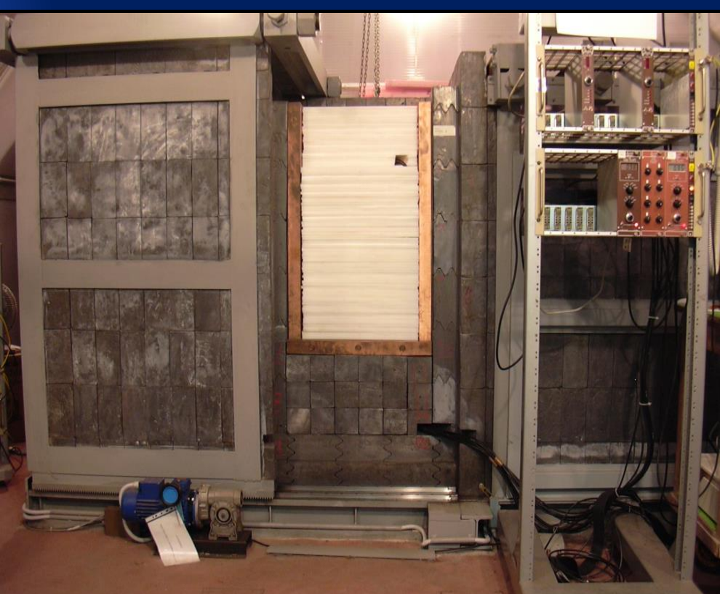
Some cosmogenic radioisotopes measurable in meteorites ($T_{1/2}$ > 0.5 month)

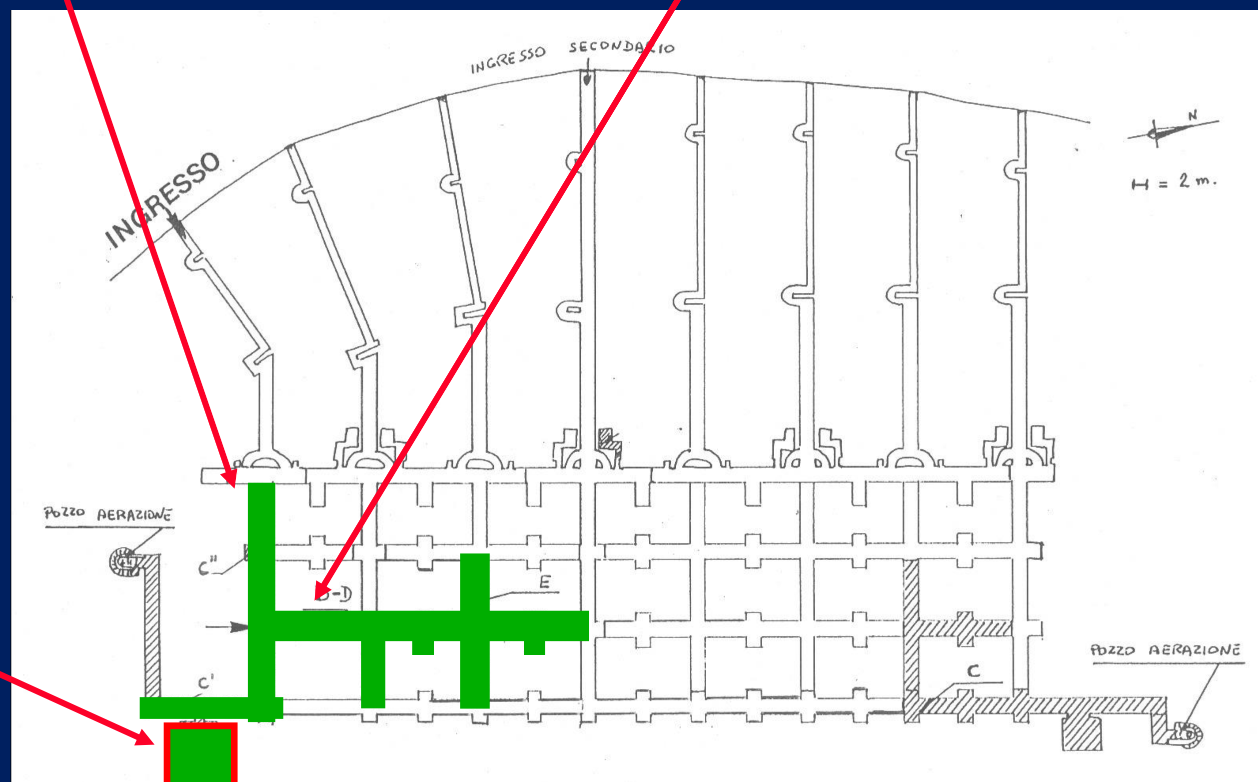
Nuclide	Half-life	Main target elements
^{48}V	0.0438 a	Ti, Fe, Ni
^{51}Cr	0.0759 a	Fe, Ni
^{37}Ar	0.096 a	Ca, Ti, Fe, Ni
^{7}Be	0.146 a	C,O, Mg, Al, Si, S*, P*, Ca, Ti, Fe, Ni
^{58}Co	0.194 a	Fe$^{(\alpha)}$, Ni
^{56}Co	0.213 a	Fe, Ni
^{46}Sc	0.230 a	Ti, Fe, Ni
^{57}Co	0.743 a	Fe, Ni
^{54}Mn	0.855 a	Fe, Ni, Mn
^{22}Na	2.6 a	Mg, Al, Si, Ca, Ti, Fe, Ni
^{55}Fe	2.7 a	Mn, Fe, Ni
^{60}Co	5.26 a	Co$^{(n)}$, Ni
^{3}H	12.3 a	C, O, Mg, Al, Si, S*, P*, Ca, Ti, Fe, Ni
^{44}Ti	59.2 a	Ti, Fe, Ni
^{32}Si	133 a	Ca, Ti, Fe, Ni
^{39}Ar	269 a	Ca, Ti, Fe, Ni
^{14}C	5.73 ka	O, Mg, Al, Si, S*, P*, Ca, Ti, Fe, Ni
^{59}Ni	75 ka	Fe$^{(\alpha)}$, Ni
^{41}Ca	103 ka	Ca$^{(n)}$, Ti, Fe, Ni
^{81}Kr	210 ka	Rb, Sr, Y, Zr
^{36}Cl	300 ka	Cl$^{(n)}$, Ca, Ti, Fe, Ni
^{26}Al	716 ka	Mg, Al, Si, S*, P*, Ca, Ti, Fe, Ni
^{60}Fe	1.5 Ma	Ni
^{10}Be	1.51 Ma	C, O, Mg, Al, Si, S*, P*, Ca, Ti, Fe, Ni
^{53}Mn	3.7 Ma	Fe, Ni
^{129}I	15.7 Ma	Te$^{(n)}$, Ba, REE
^{40}K	1.28 Ga	Ca, Ti, Fe, Ni
^{3}He	stable	C, O, Mg, Al, Si, S*, P*, Ca, Ti, Fe, Ni
^{21,22}Ne	stable	Na, Mg, Al, Si, S*, P*, Ca, Ti, Fe, Ni
^{36,38}Ar	stable	Cl$^{(n)}$, Ca, Fe, Ni
$^{78-80,82-84}$Kr	stable	Br$^{(n)}$, Rb, Sr, Y, Zr
$^{124-132}$Xe	stable	Te, I$^{(n)}$, Ba$^{(n)}$, REE

Michel and Neumann, 1978

In Torino meteorite also ^{52}Mn ($T_{1/2}$ = 5.6 d), ^{47}Sc (3.35 d), ^{57}Ni (36 h), ^{48}Cr (21.6 h), ^{24}Na (15 h) have been measured

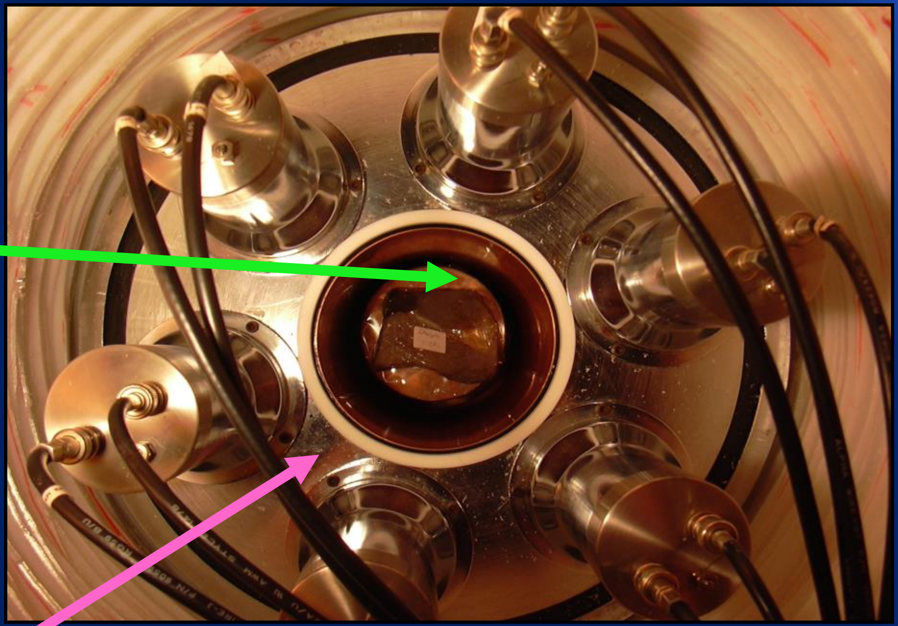
Laboratory of Monte dei Cappuccini (INAF) - 70 m.w.e.





Experimental set-up:
Large volume γ-ray spectrometer

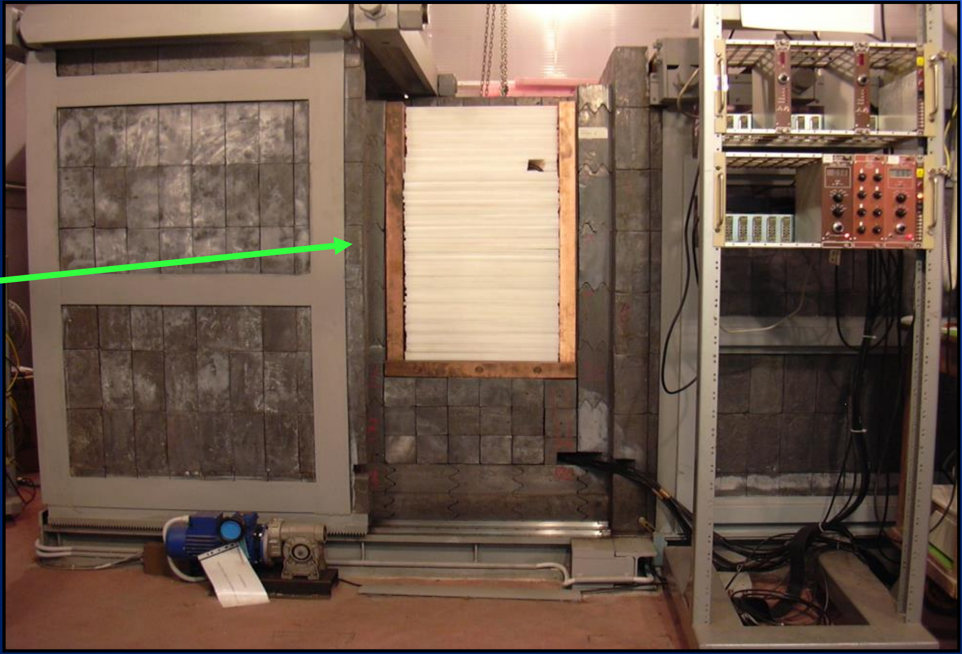
- HPGe crystal: ~3 kg
  - relative efficiency ~ 150%
  - At 1332 keV of ^{60}Co
    resolution (FWHM) = 1.85 keV
    peak to Compton ratio = 104



- surrounded by NaI(Tl)

  anulus + *plug* (~ 90 kg)
  with 7 photomultipliers

- Detectors are housed in a 20 cm thick <u>lead</u> shield, internally lined with 1 mm of <u>Cd</u>, 5 cm OFHC copper and <u>polythene</u> in the empty spaces.



- located in the underground (70 m.w.e.) Laboratory of Monte dei Cappuccini (Torino)

Large samples (~1 kg) can be counted reliably and with high specificity

Dhajala (1976)

Albareto (1766)

Cereseto (1840)

Dergaon (2001)

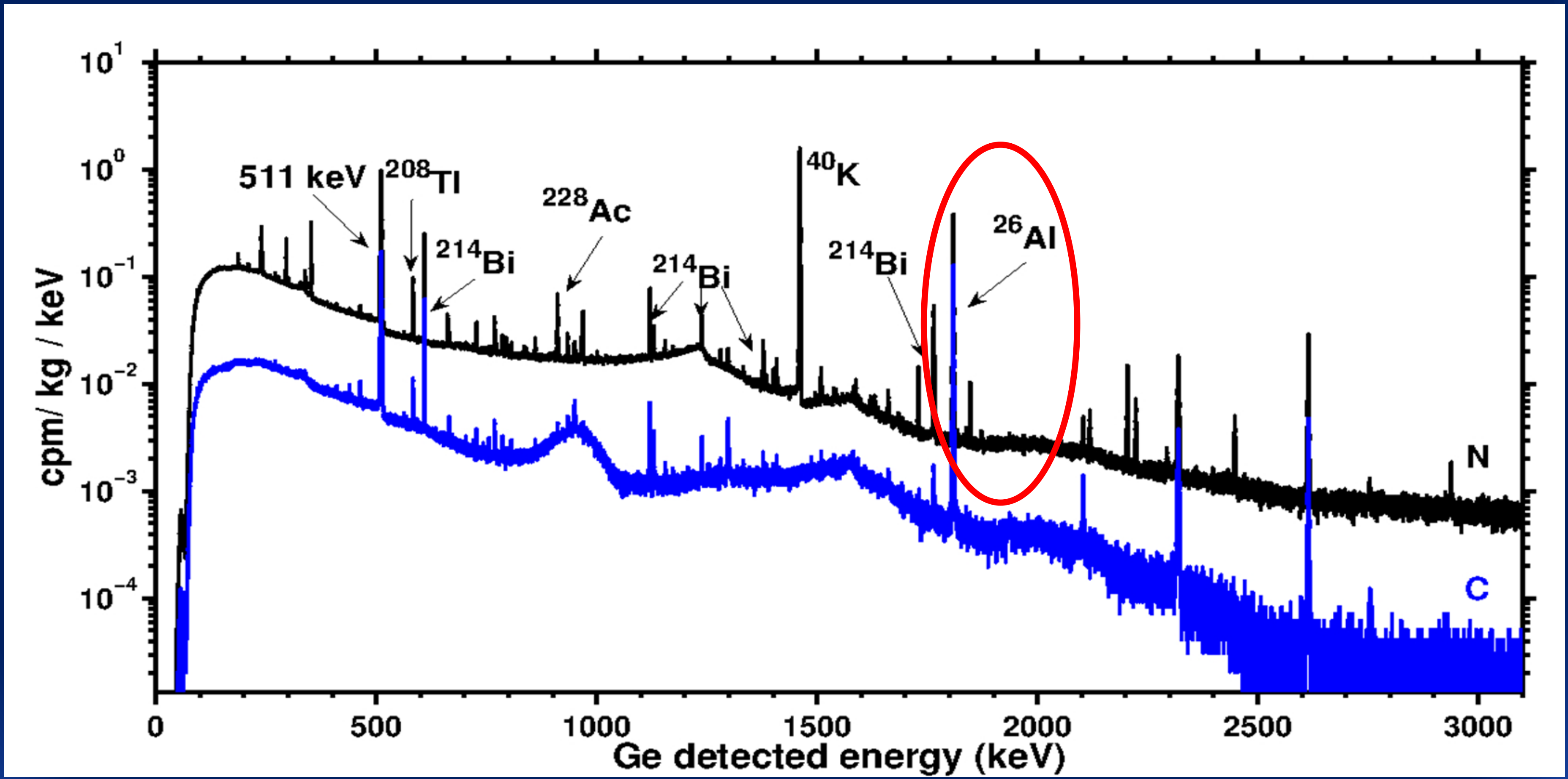
Allegan (1899)

Meteorites suitable for our studies:

- **Known date of fall**
- **Suitable mass**
- **Shape compatible with our detectors**

Meteorite	Class	Date of fall	Sample mass (g)	Recovered mass (kg)	Source
Tabor	H5	03 / 07 / 1753	669	7.54	University of Budapest
Albareto	LL4	July 1766	580	2	Modena Museum
Mooresfort	H5	August 1810	1145	3.5	National Museum, Ireland
Charsonville	H5	23 / 11 / 1810	524	27	NHM, Vienna
Agen	H5	5 / 9 / 1814	683	30	Vatican Obs. Rome
Cereseto	H5	17 / 7 / 1840	1308	6.46	Museo di scienza naturale, Torino
Grüeneberg	H4	22 / 3 / 1841	717	1	MFN, Berlin
Kernouve’	H6	22 / 5 / 1869	820	80	NHM, Vienna
Alfianello	L6	16 / 2 / 1883	625	228	Vatican Obs. Rome
Allegan	H5	10 / 7 / 1899	296	42	Vatican Obs. Rome
Bath	H4	29 / 8 / 1892	539	21	NHM, Vienna
Lancon	H6	20 / 6 / 1897	1080	7	Vatican Obs. Rome
Holbrook	L6	19 / 7 / 1912	331	220	Vatican Obs. Rome
Olivenza	LL5	19 / 6 / 1924	247	150	Vatican Obs. Rome
Rio Negro	L4	21 / 9 / 1934	388	1.31	Vatican Obs. Rome
Monze	L6	5 / 10 / 1950	165	?	Vatican Obs. Rome
Sinnai 3 Sinnai 4	H6	19 / 02 / 1956	350 351	2	University of Cagliari
Dhajala	H3/4	28 / 1 / 1976	706	45	PRL, India
Torino	H6	19 / 5 / 1988	445	0.977	Alenia, Torino
Mbale A Mbale T	L5	14 / 8 / 1992	700 730	150	DMS, Denmanrk
Fermo	H3	25 / 9 / 1996	800	10.2	Municipio di Fermo
Dergaon	H5	2 / 3 / 2001	1330	>12	Gauhati University, India
Gebel Kamil 1 Gebel Kamil 2	Iron meteorite	Unknown	672 450	7.54	Private
Almahata Sitta	Ureilite	07/10/2008	75	3.95	NASA

γ-ray spectrum of Agen meteorite



Agen, 1814 *(Taricco et al., Astr. and Sp. Sc., 2016)*

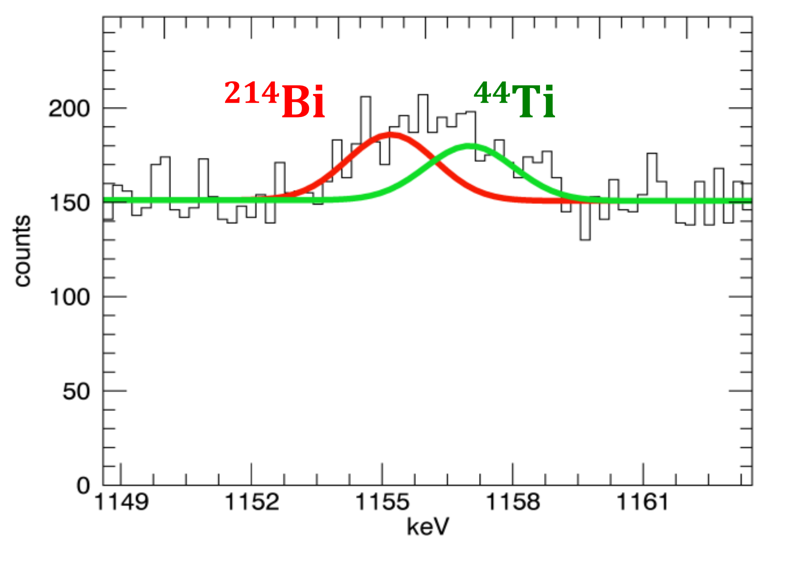
Proxy for centennial and multicentennial scale solar variations:

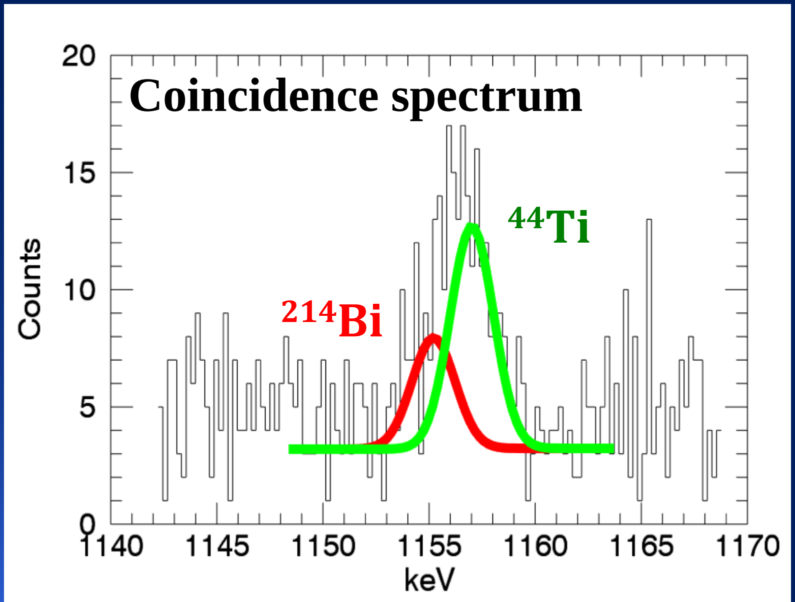
^{44}Ti ($T_{1/2}$ = 59.2 years)

Our group measured for the first time in a reliable way the activity of the ^{44}Ti in meteorites. This is the unique and direct method to reconstruct solar activity variations in the last centuries

In order to attribute the activity variations to the cosmic ray intensity, it is necessary to correct the measured activity for

- Target element abundances
- Shielding depth in the meteoroid (nuclear tracks)
- ^{44}Ti decay after the fall

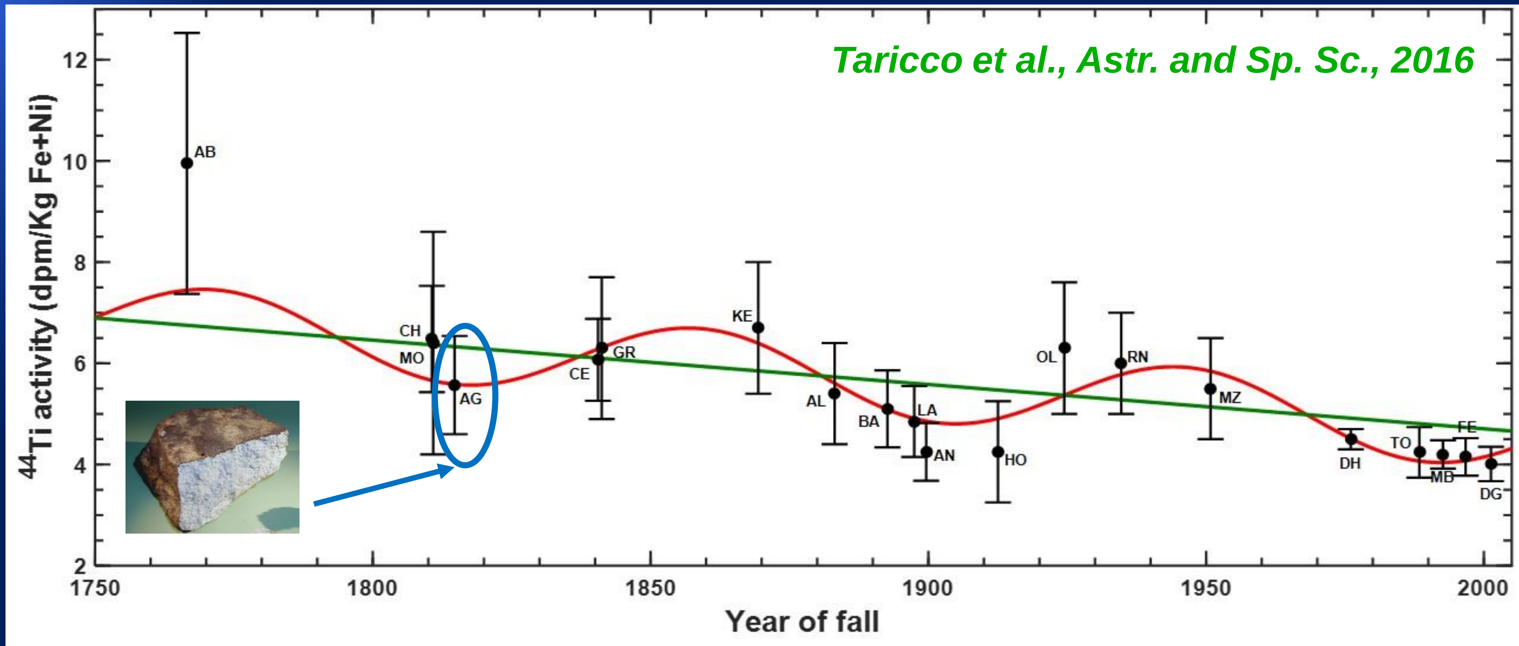




Ge – NaI coincidence method

Reduction of the interference of natural radionuclides

Dhajala (1976, India)



Albareto (AB)
Charsonville (CH)
Mooresfort (MO)
Agen (AG)
Cereseto (CE)
Gruneburg (GR)
Kernouvè (KE)
Alfianello (AL)
Bath (BA)
Lancon (LA)
Allegan (AN)
Holbrook (HO)
Olivenza (OL)
Rio Negro (RN)
Monze (MZ)
Dhajala (DH)
Torino (TO)
Mbale (MB)
Fermo (FE)
Dergaon (DG)

Decreasing trend of ^{44}Ti activity of ~ 40% (decrease of GCR flux) during the past 235 years

A ~ 90 year oscillation reveals GCR flux maxima (solar activity minima) around 1800 and 1900

The activity of ^{44}Ti in the 5 most recent falls (1976 – 2001) shows the solar activity was unusually higher during the present epoch compared to the past two centuries

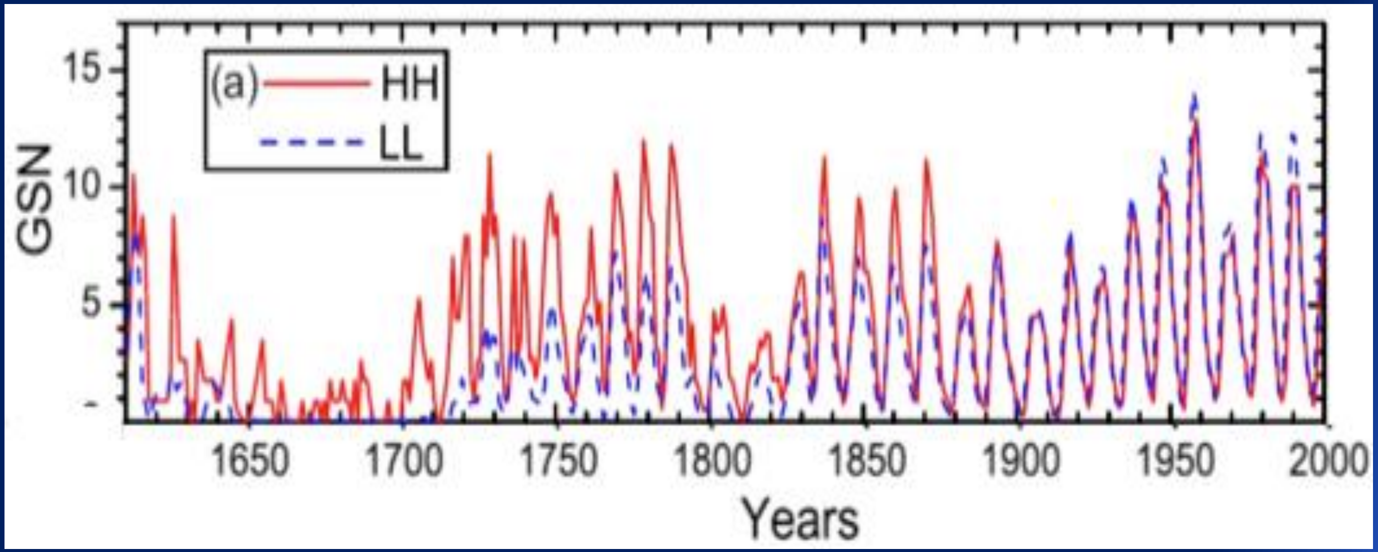
The measurement of recently-fallen meteorites would improve the estimation of the long-term trend and of the centennial oscillation

Monthly Notices
of the
ROYAL ASTRONOMICAL SOCIETY
MNRAS **467,** 1608–1613 (2017) doi:10.1093/mnras/stx190
Advance Access publication 2017 January 22

Assessment of different sunspot number series using the cosmogenic isotope ^{44}Ti in meteorites

Eleanna Asvestari,[1] Ilya G. Usoskin,[1,2★] Gennady A. Kovaltsov,[3] Mathew J. Owens,[4★] Natalie A. Krivova,[5] Sara Rubinetti[6,7] and Carla Taricco[6,7]

Different SN series describing different levels of solar activity are available:



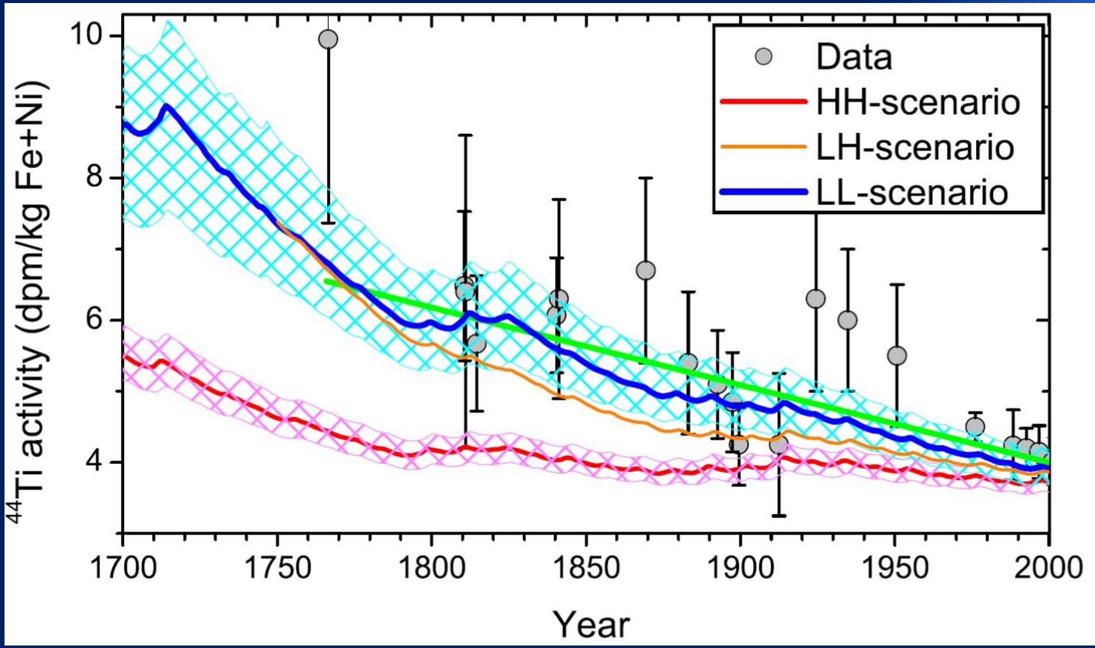
- **HH-scenario** ***(Svalgaard and Schatten, 2016)*****:** highest activity during and after the Maunder minimum
- **LL-scenario** ***(Lockwood et al., 2014):*** very low activity level for the Maunder minimum and over 1750-1900
- **LH-scenario: a composite of the LL-scenario before 1750 and the HH-scenario after 1750**

SN series

magnetic open solar flux

heliospheric modulation parameter

^{44}Ti activity



Both the LL- and LH-scenarios are fully consistent with the ^{44}Ti data while the HH scenario can be rejected on the basis of ^{44}Ti measurements

Our measurements reveal that the most reliable SN series reaches near-to-zero values during the Maunder minimum (blue curve)

Conclusions

- In the frame of the PRISMA project, we plan (hope) to measure
- γ-activity of recently-fallen meteorites in order to:
  - detect radionuclides with short half-lives
  - improve the knowledge of solar activity long-term variation

- Besides the experimental activity, we are implementing numerical simulations (GEANT4) in order to determine the detection efficiency of cosmogenic activity in meteorites using Ge-NaI spectrometers *(in collaboration with LNGS, INFN)*

THANK YOU
FOR
YOUR ATTENTION