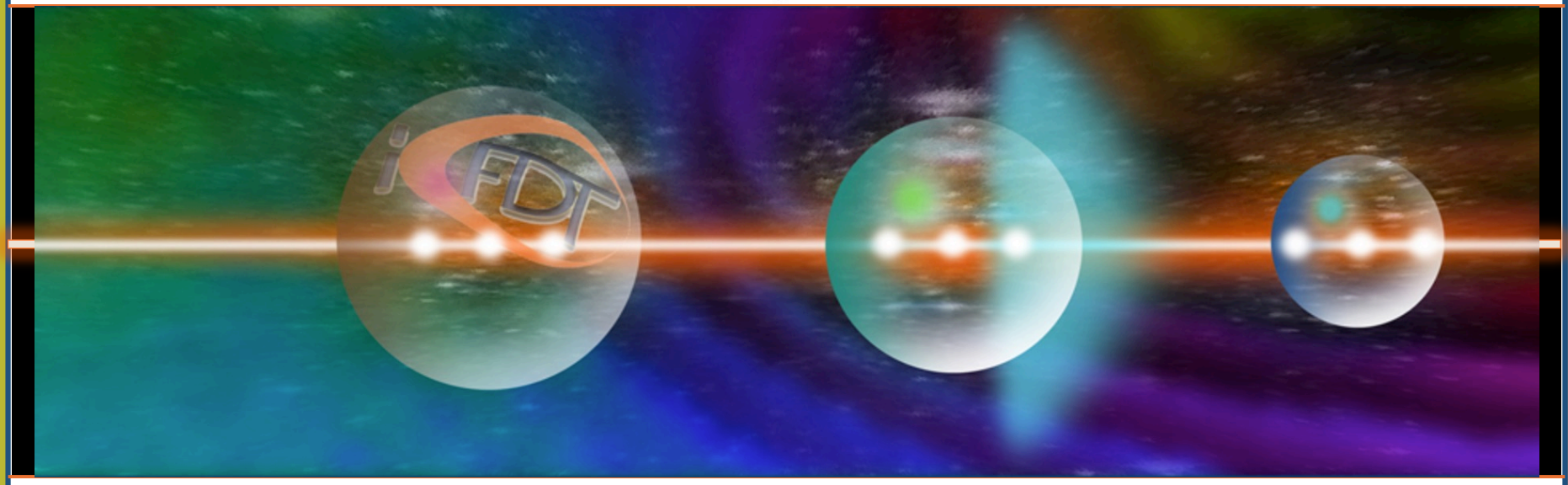
INFN - Laboratori Nazionali di Frascati
21-23 October, 2024
Frascati (Rome) Italy - Auditorium B. Touschek



^{14}C Dating, paleoclimatic and paleofood research using Carbon and Nitrogen stable isotopes

F. Marzaioli, F. Terrasi, G. Porzio, I. Passariello, Frangipane M.

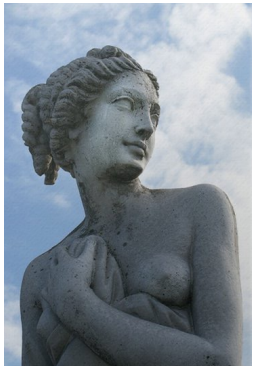
Prof. Fabio Marzaioli
fabio.marzaioli@unicampania.it

Istituto Nazionale di Fisica Nucleare

Università degli Studi della Campania *Luigi Vanvitelli*
Dipartimento di Matematica e Fisica

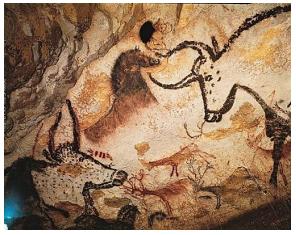
Cultural Heritage (CH)

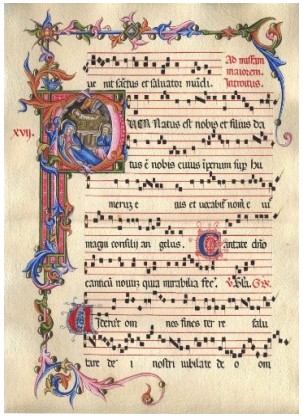


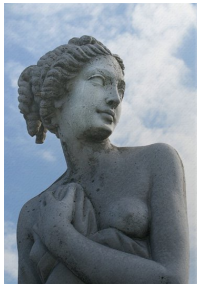




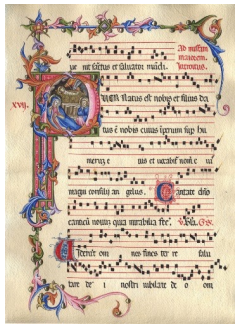



Archaeometry

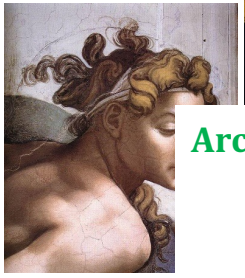







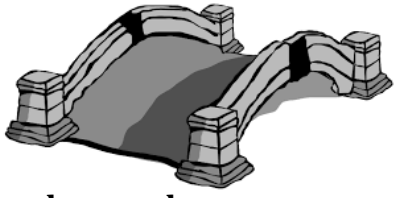






Archaeometry: an interdisciplinary research area where complementary approaches cooperate to investigate CH materials

Humanities
e.g. archaeology, art, history



Natural Sciences
e.g. chemistry, physics, biology, geology

Research Laboratory of Archaeology and History of Art

1955 - Oxford University - Oxford 6 Keble Road

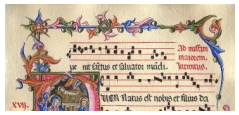
C. Hawkes and F. A. Lindemann

laboratory devoted to the application of scientific techniques to archaeology and art-history studies

Archaeometry





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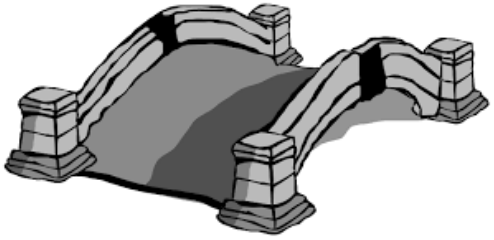

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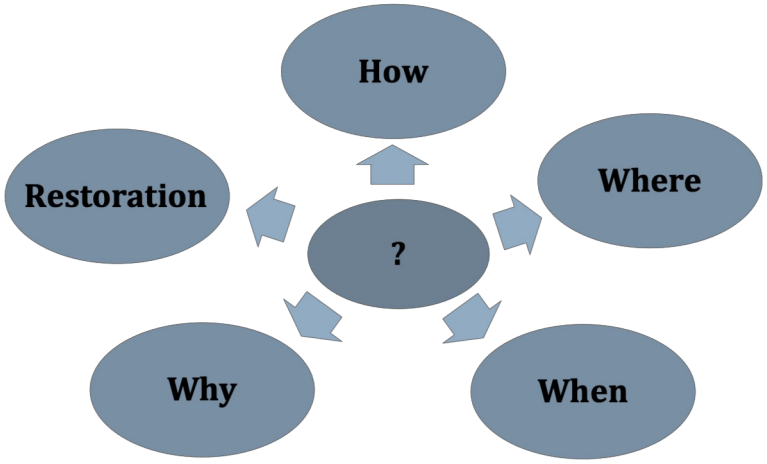
Archaeometry and CH

Answers to the archaeological questions



Archaeometry and CH

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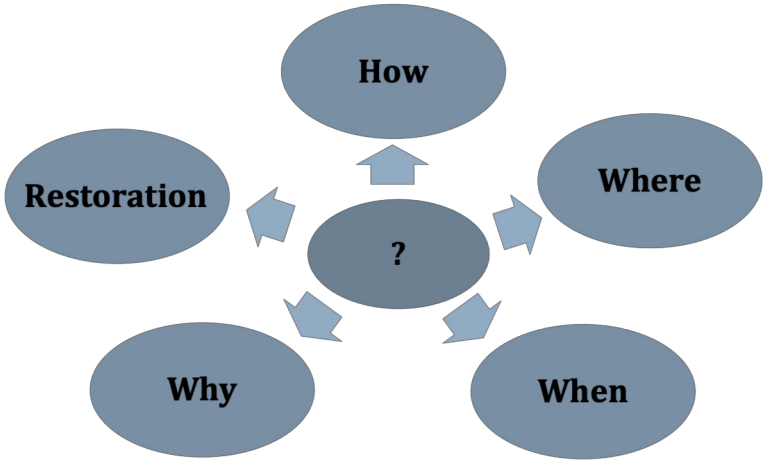
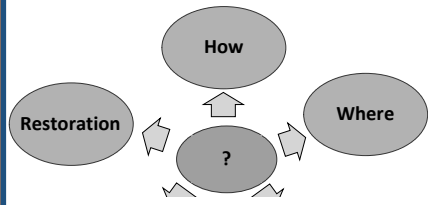


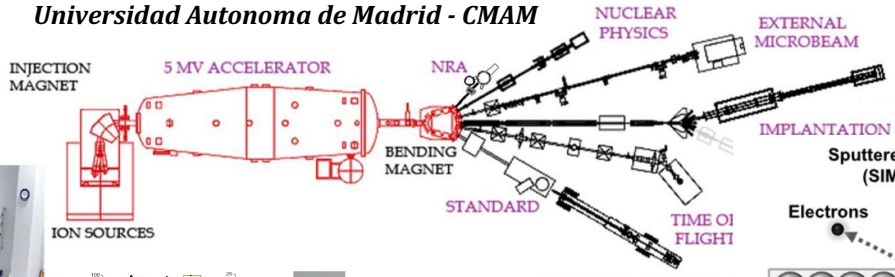
The art object act as a *storyteller* able to describe environmental, anthropological and cultural contexts

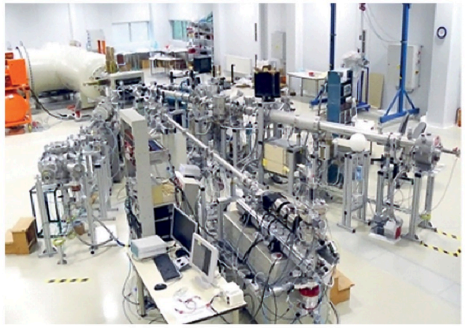
Chronolgy	Bio archaeometry
Provenance	Geo archaeometry
Material characteriz.	Production technique
Human-environment interactions	Authenticity

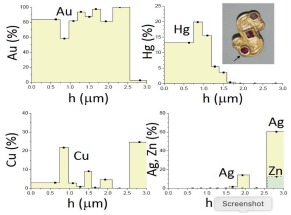
Interaction of Ion Beams with the matter



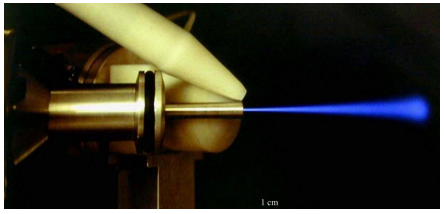
Universidad Autonoma de Madrid - CMAM

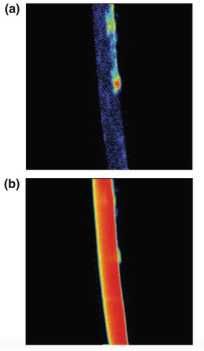


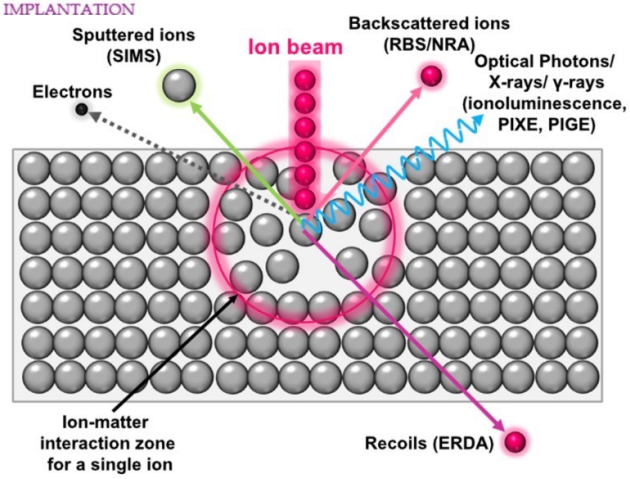




LABEC-INFN-FI



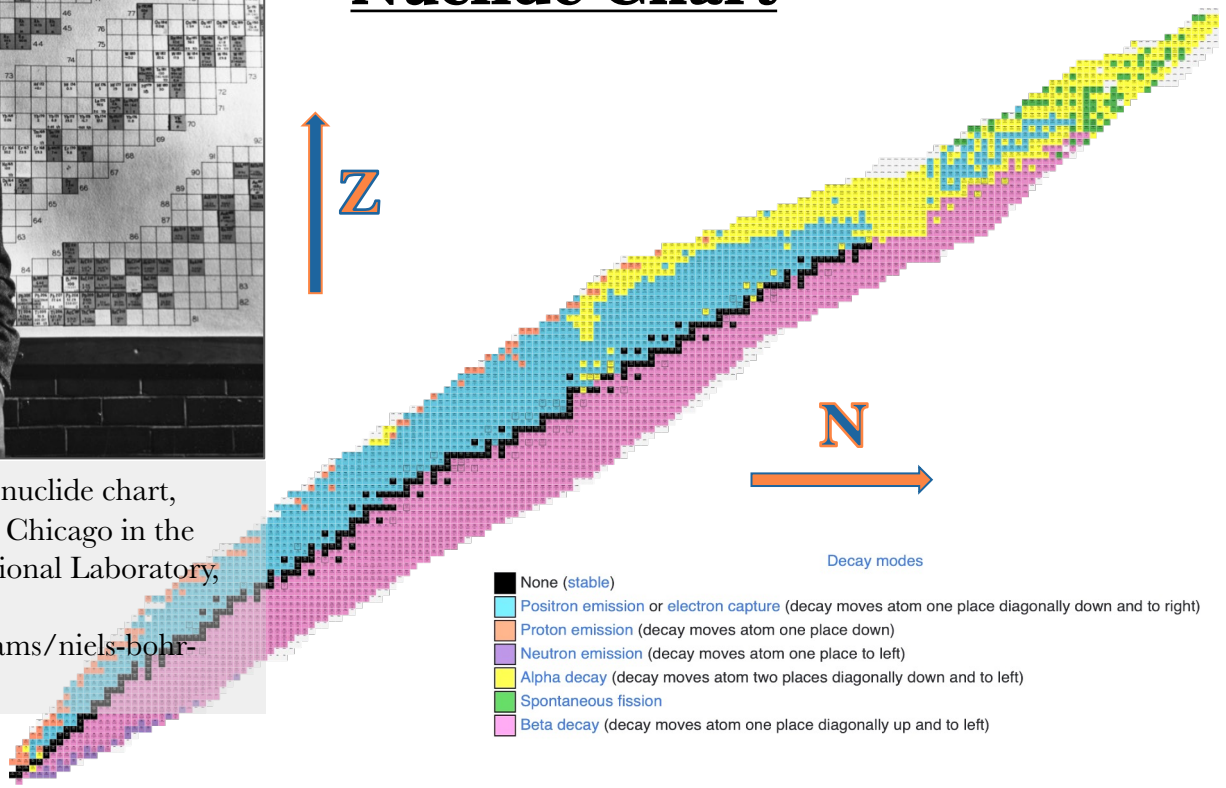




Very dense energy over short time and volume per incident ion

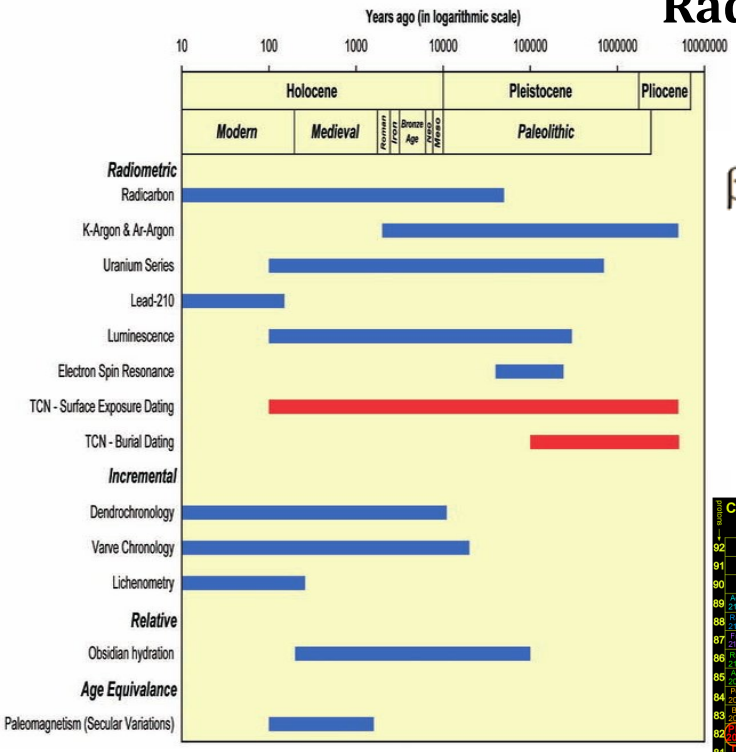
Glenn Seaborg standing in front of a nuclide chart, likely in his office at the University of Chicago in the first half of 1946. From Argonne National Laboratory, Emilio Segrè Visual Archives https://photos.aip.org/history-programs/niels-bohr-library/photos/seaborg- glenn- b10

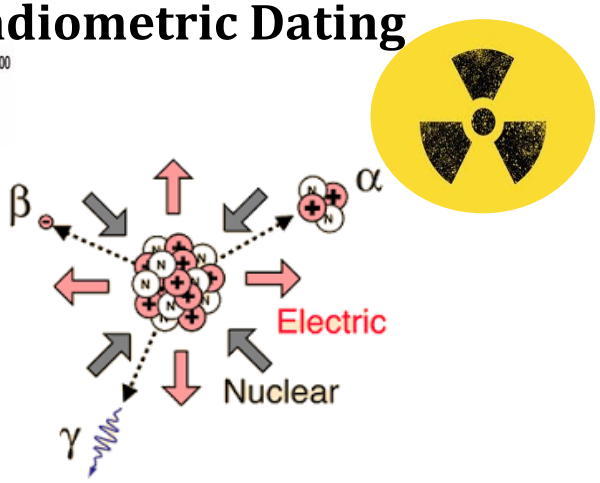
Nuclide Chart

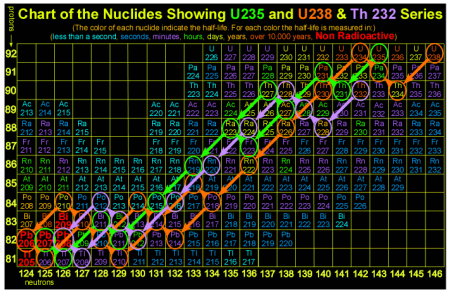


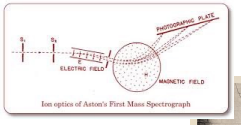
Radiometric Dating

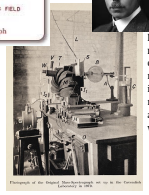
Radiometric Dating



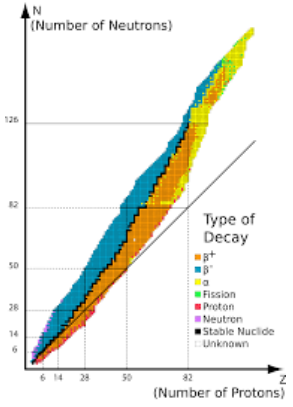




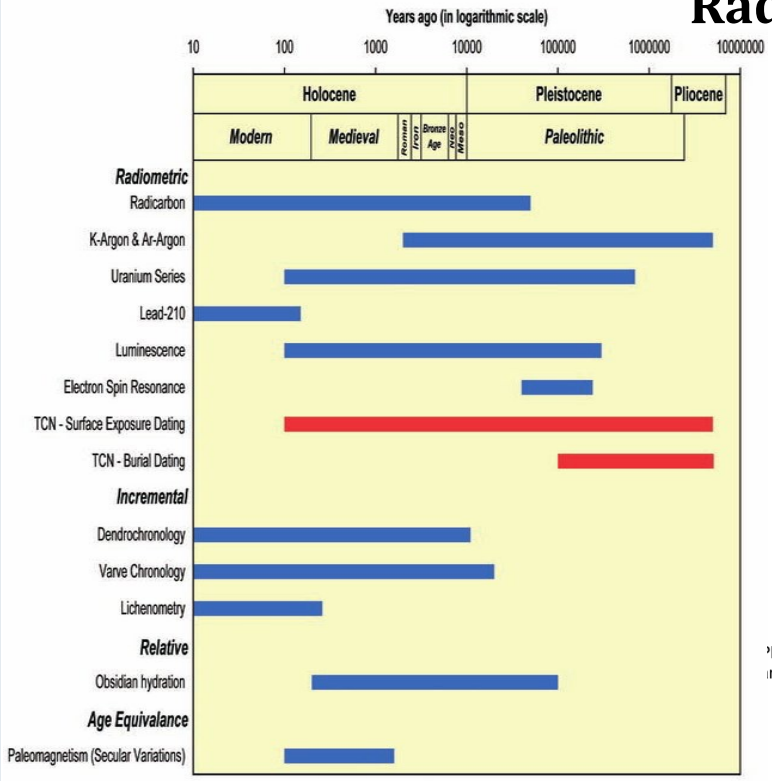


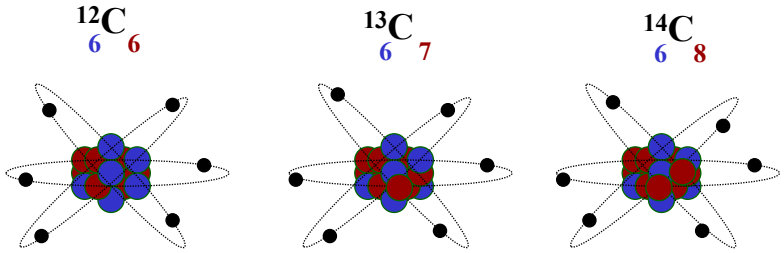


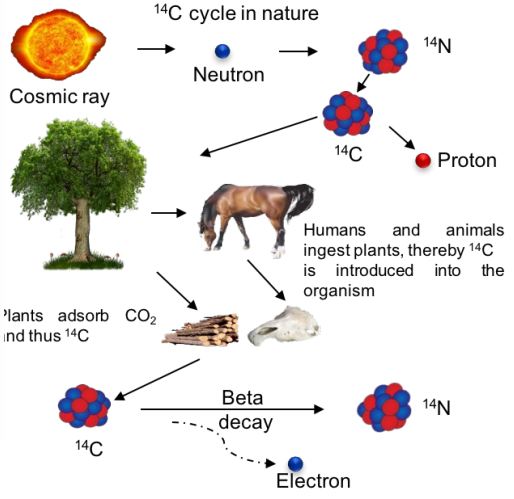
NOBEL (1922) Prize motivation: "for his discovery, by means of his mass spectrograph, of isotopes, in a large number of non-radioactive elements, and for his enunciation of the whole-number rule"

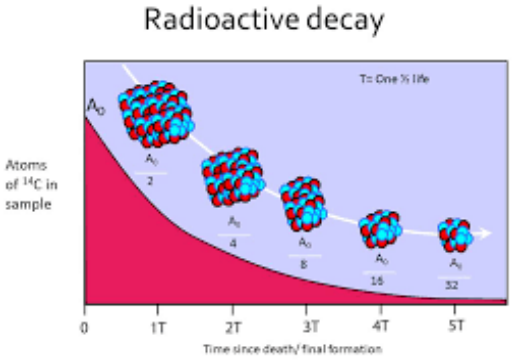


Radiocarbon Dating









^{14}C Dating

HISTORY OF RADIOCARBON DATING W. F. LIBBY

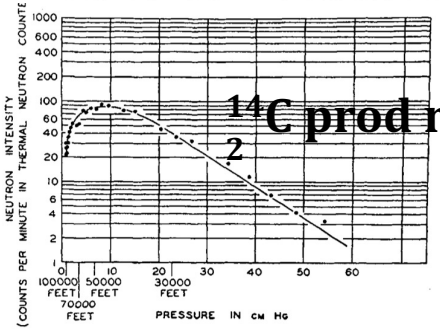
Fermi and Rome Group calculated that ^{14}N thermal neutron cross section was surprisingly high: 1.7 b predicting the presence of ^{14}C:

$$n + {}^{14}N = {}^{1}H + {}^{14}C$$

Ruben and Kamen produced and detected ^{14}C according to the reaction:

$$^{2}H + {}^{13}C = {}^{14}C + {}^{1}H$$

RUBEN, S., KAMEN, M. D., Phys. Rev. 57 (1940) 549; and ibid 58 (1940) 194.



^{14}C prod rate=2 atoms*s^{-1}*cm^{-2}

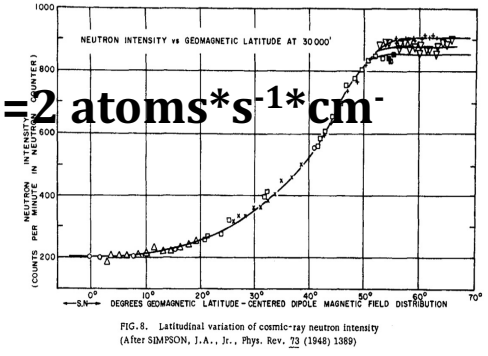
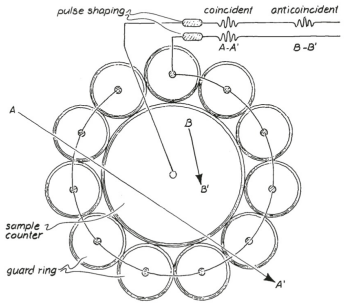
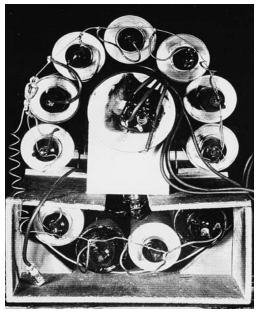
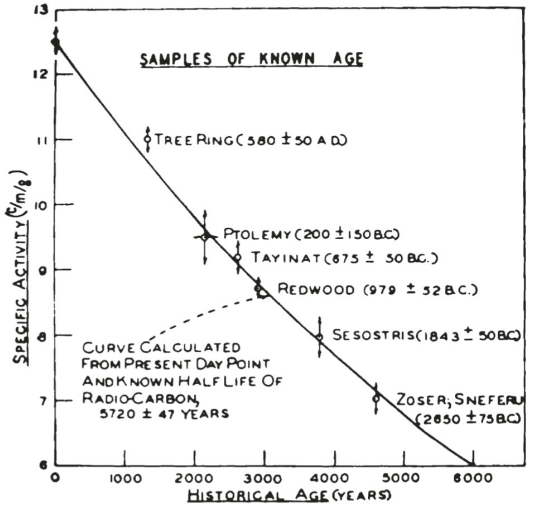


FIG. 8. Latitudinal variation of cosmic-ray neutron intensity (After SIMPSON, J.A., Jr., Phys. Rev. 73 (1948) 1389)

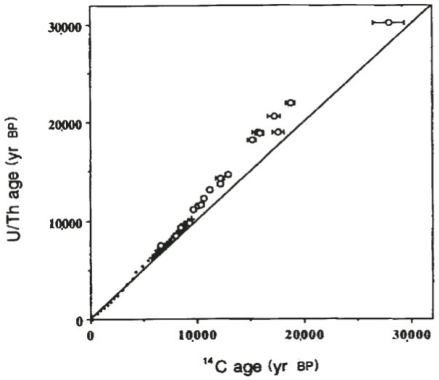


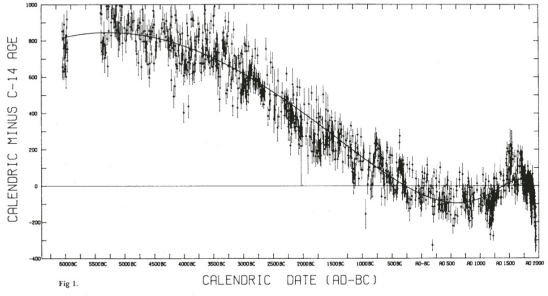




^{14}C Dating

HISTORY OF RADIOCARBON DATING





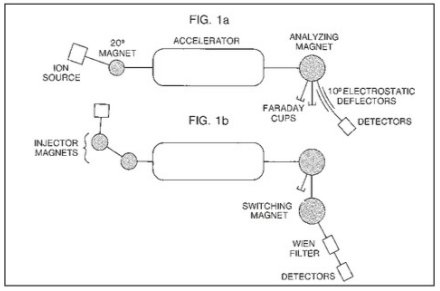
SCIENCE

29 April 1977, Volume 196, Number 4289

Radioisotope Dating with a Cyclotron

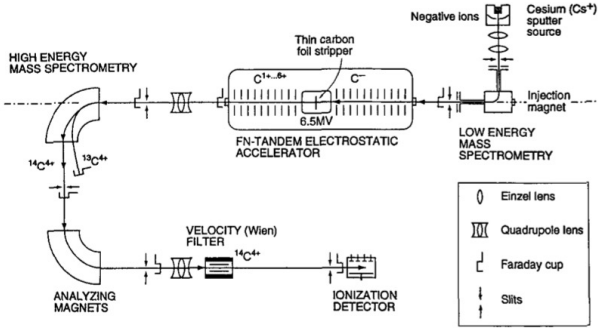
The sensitivity of radioisotope dating is improved by counting atoms rather than decays.

Richard A. Muller

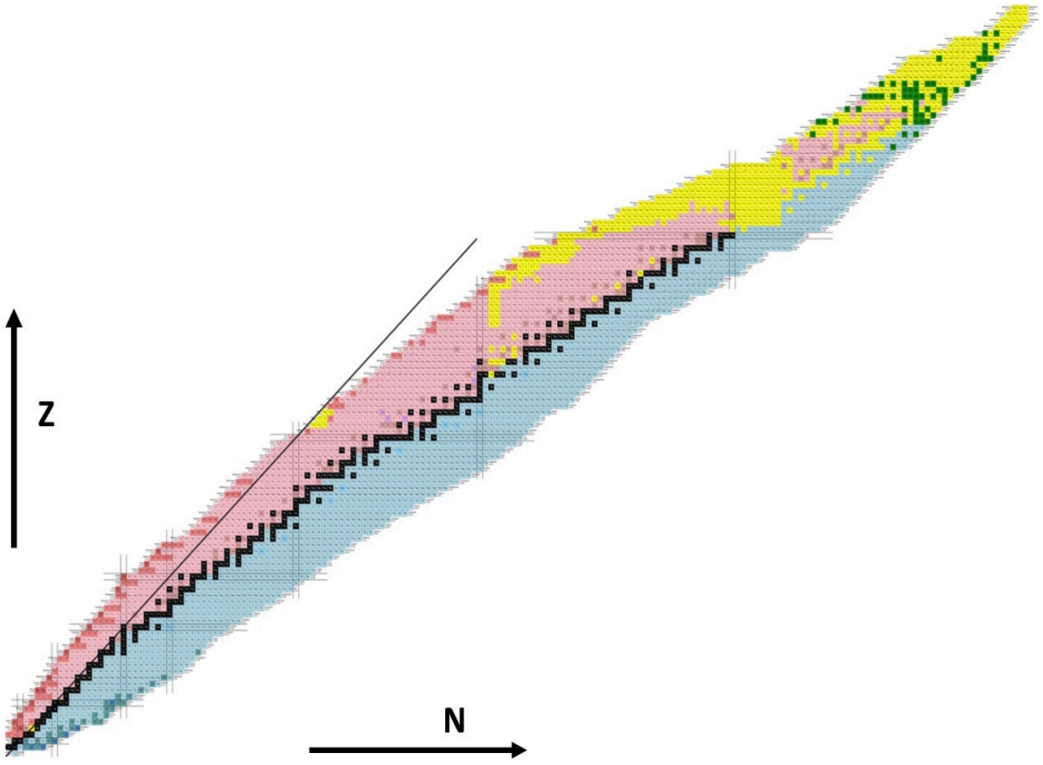


Nelson DE, Korteling RG, Scott WR (1977) Carbon-14: Direct detection at natural concentrations. Science 198: 507-508.

Bennett CL, Beukens RP, Clover MR, Gove HE, Liebert RB, Litherland AE, Purser KK,Sondheim WE (1977) Radiocarbon dating using accelerators: Negative ions provide the key. Science 198: 508-509.



Stable Isotopes



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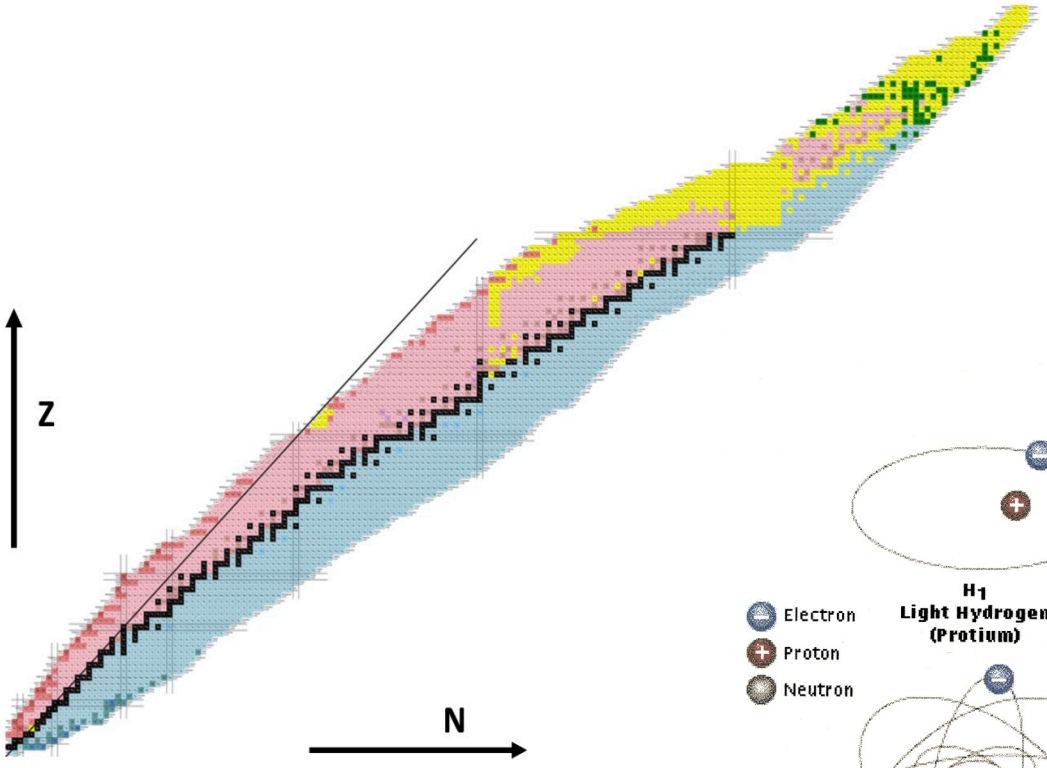

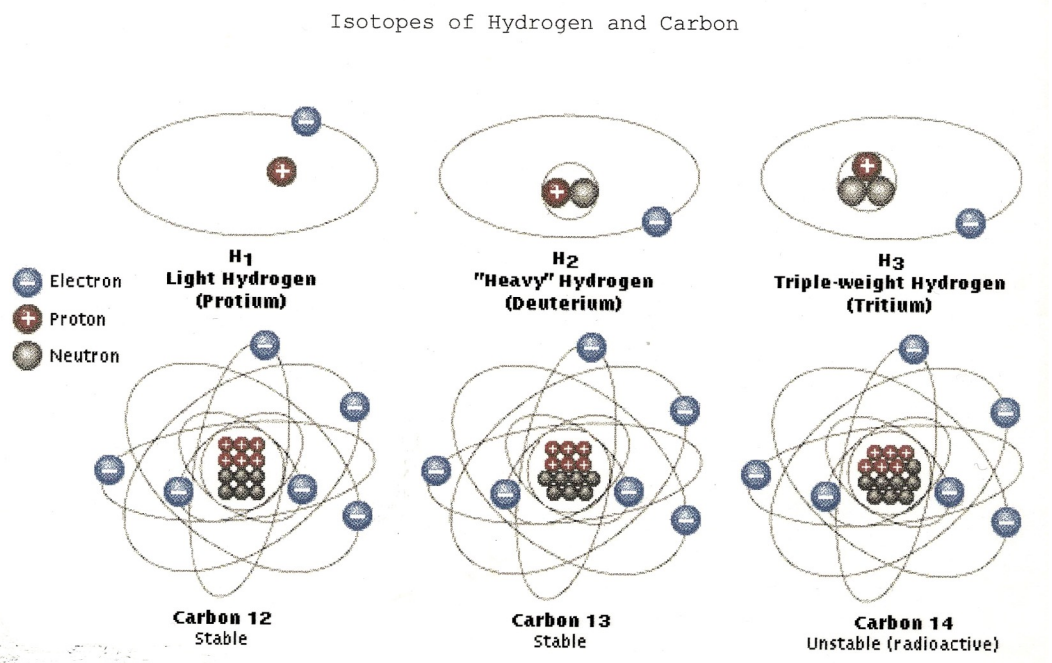

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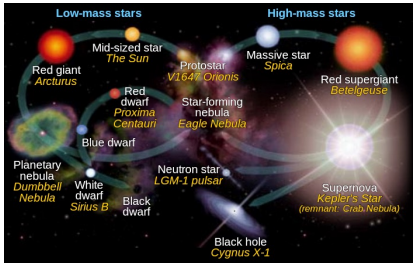
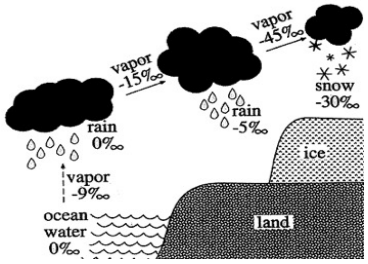
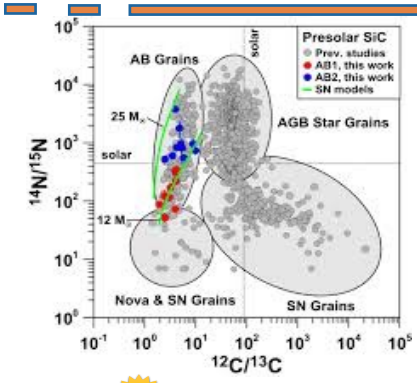
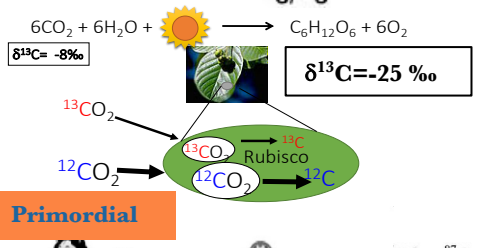
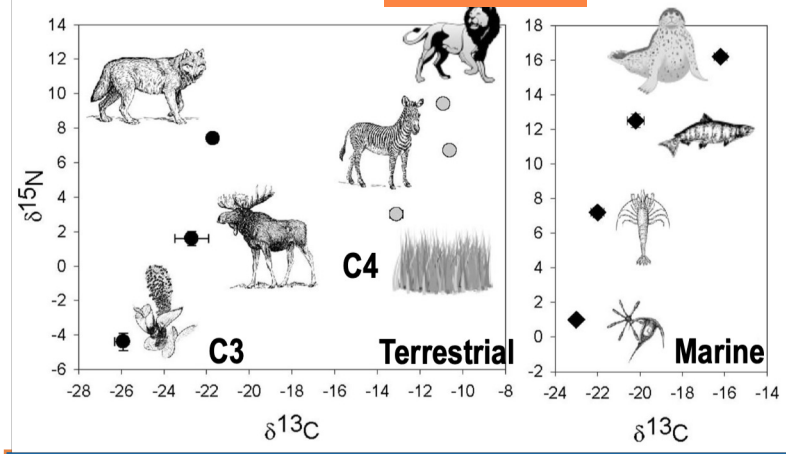




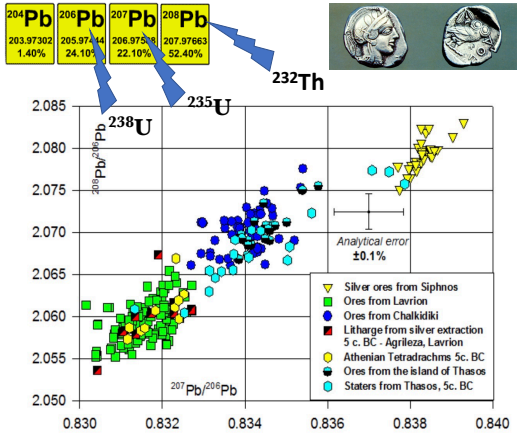




Primordial



Radiogenic



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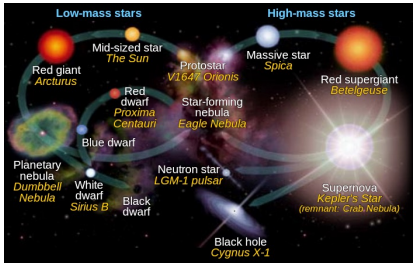
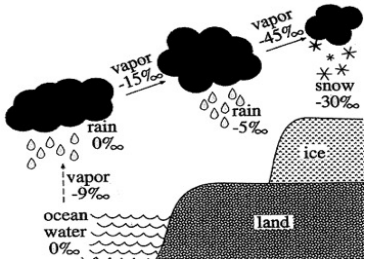
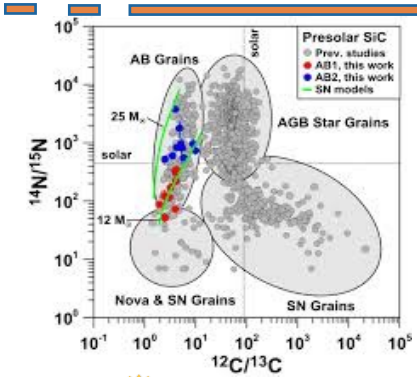
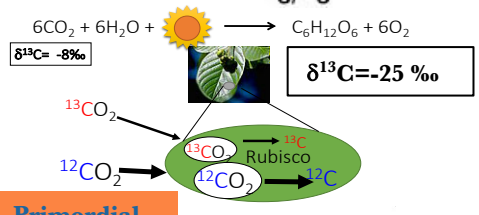


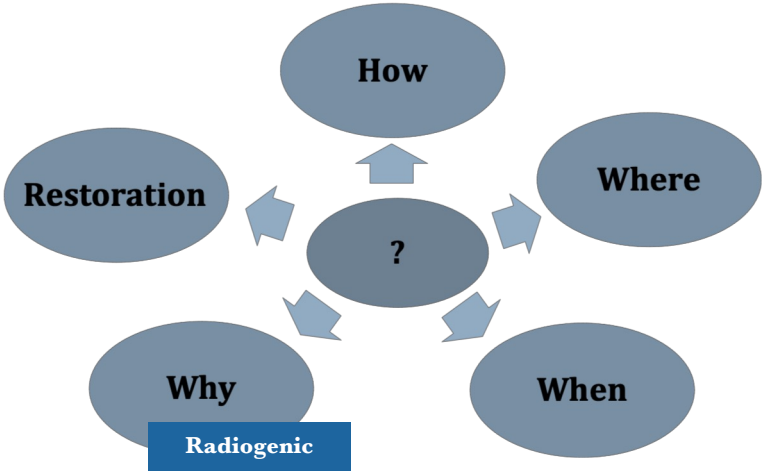






Primordial

Answers to the archaeological questions



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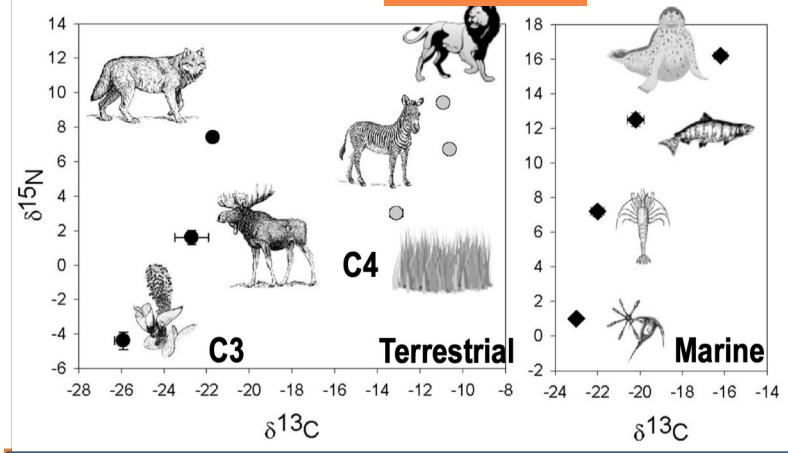
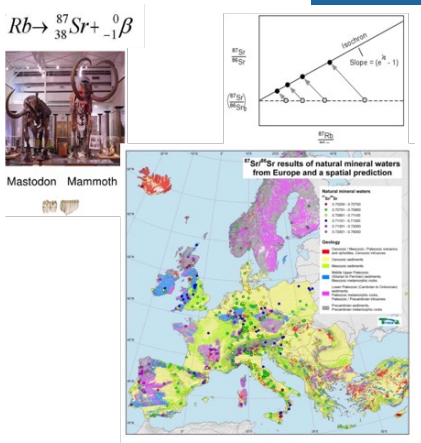
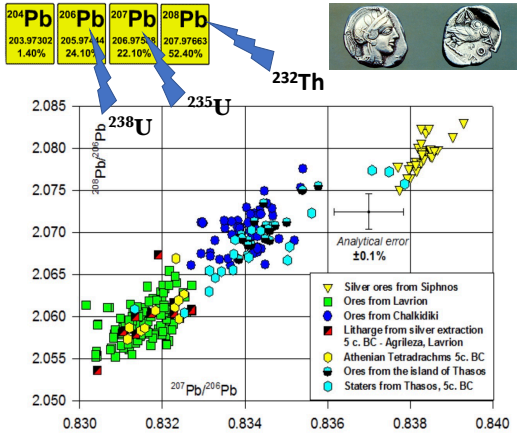
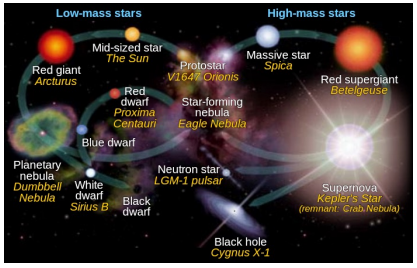
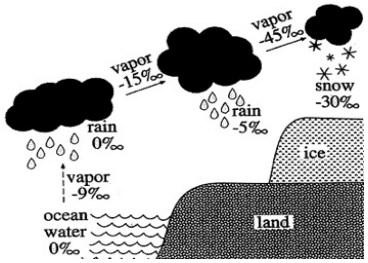


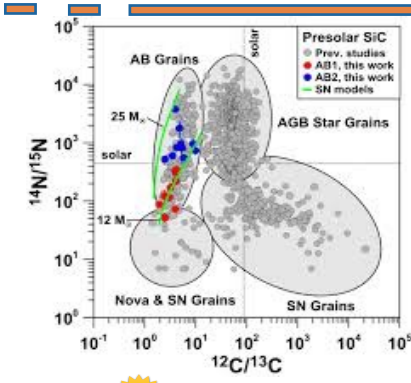


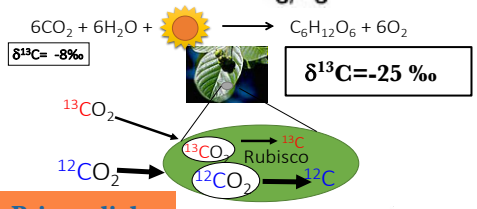


Stable Isotopes

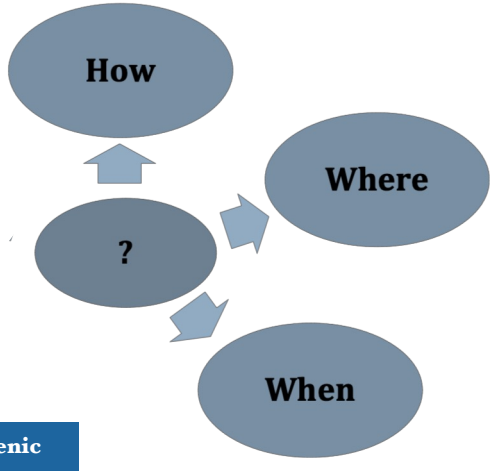




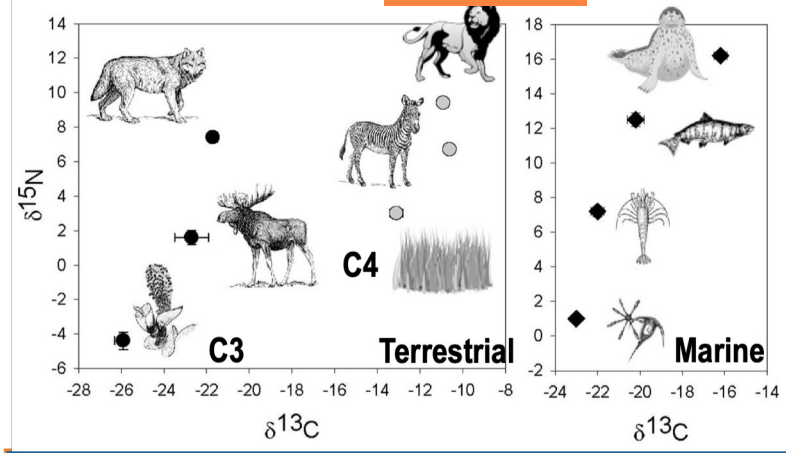




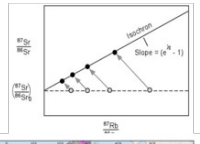
Answers to the archaeological questions

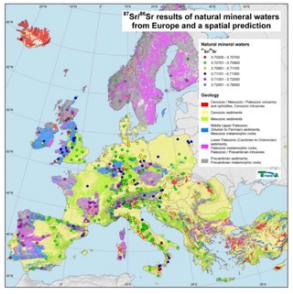


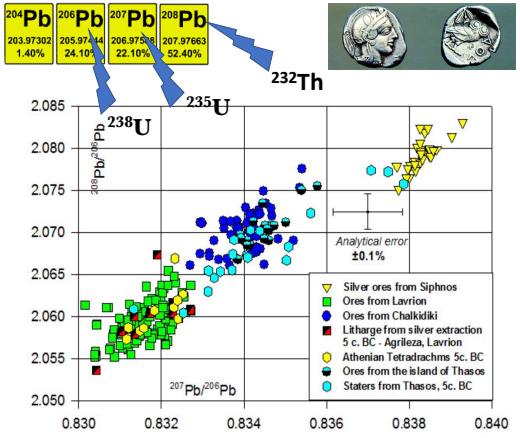
Primordial



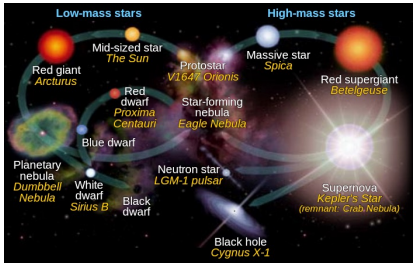
Radiogenic

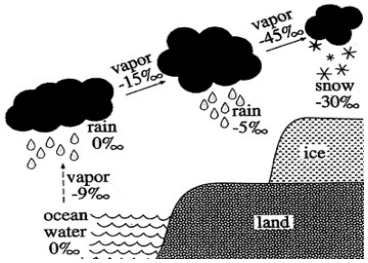


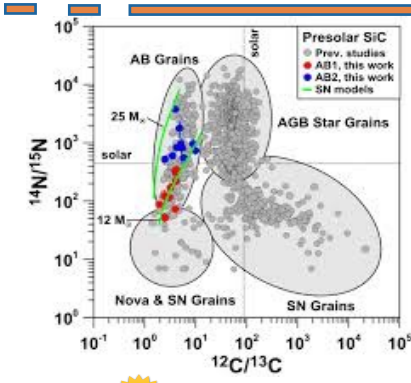


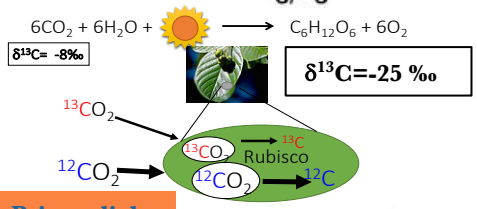


Stable Isotopes

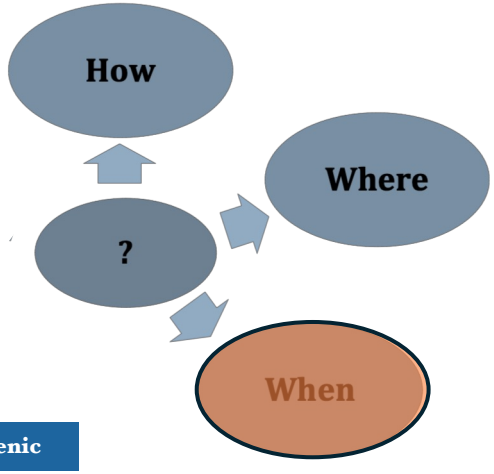




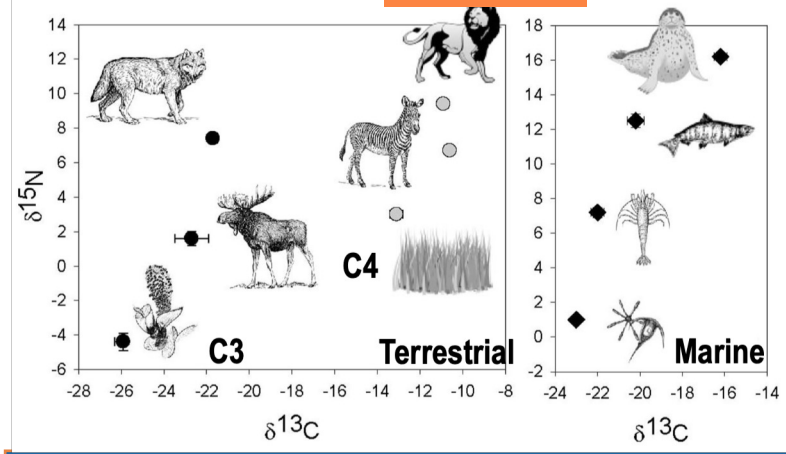




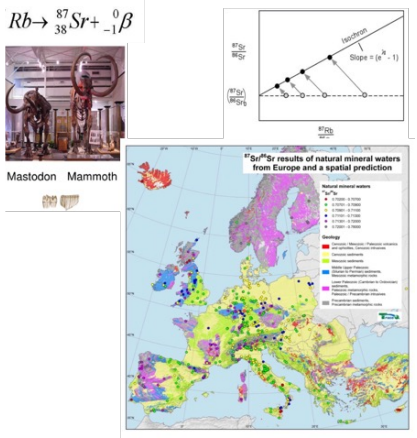
Answers to the archaeological questions

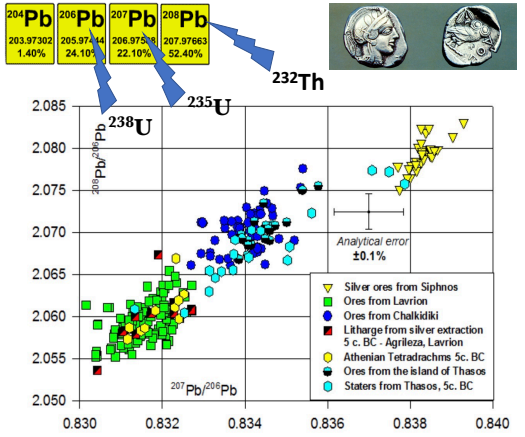


Primordial



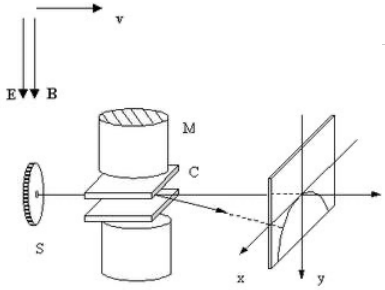
Radiogenic

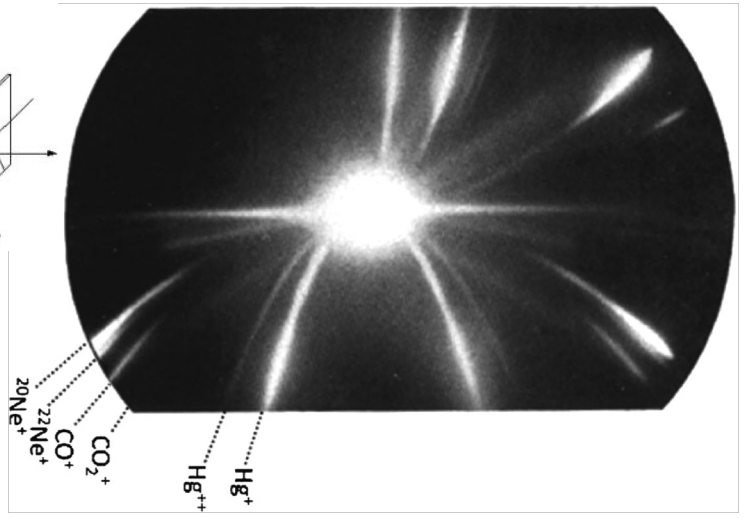


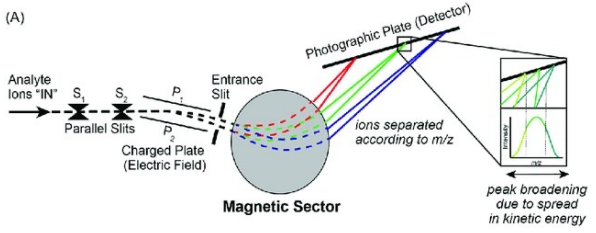


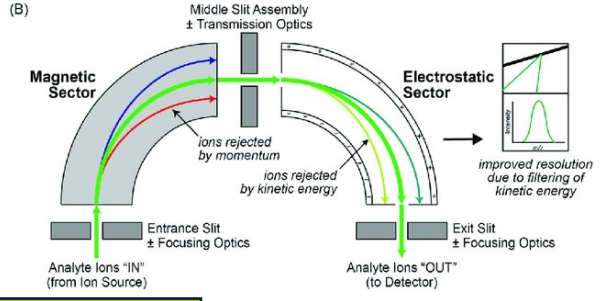
Mass Spectrometry

- 1906 : Thomson received the Nobel Prize for his work on electrons and later firstly discovered Ne isotopes with Aston.
- 1922 : Aston received the Nobel Prize for the discovery of 212 of the naturally occurring isotopes;
- 1930's : Urey developed the theory of isotope geochemistry and received the Nobel Prize for the discovery of Deuterium
- 1940's : Nier developed the first IRMS, a double-focusing double inlet MS





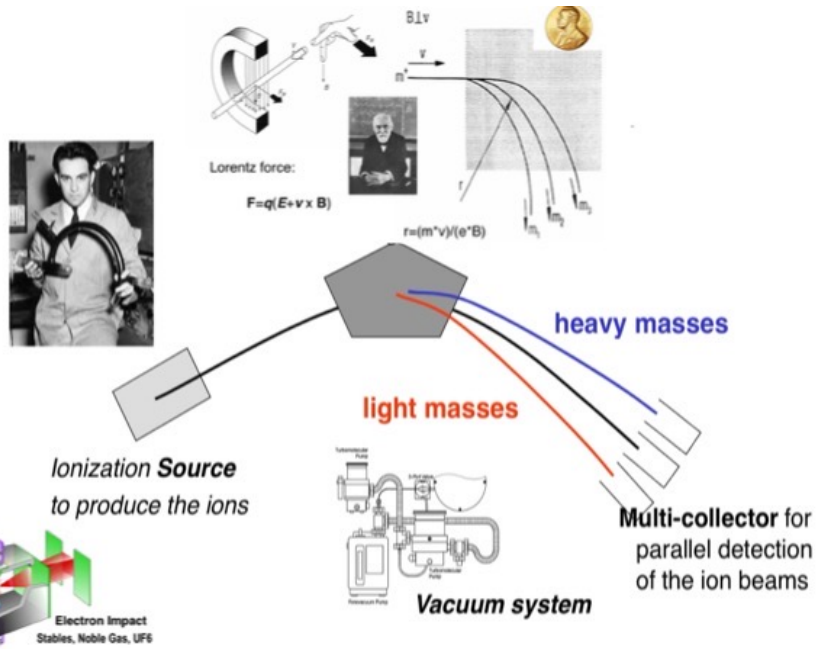




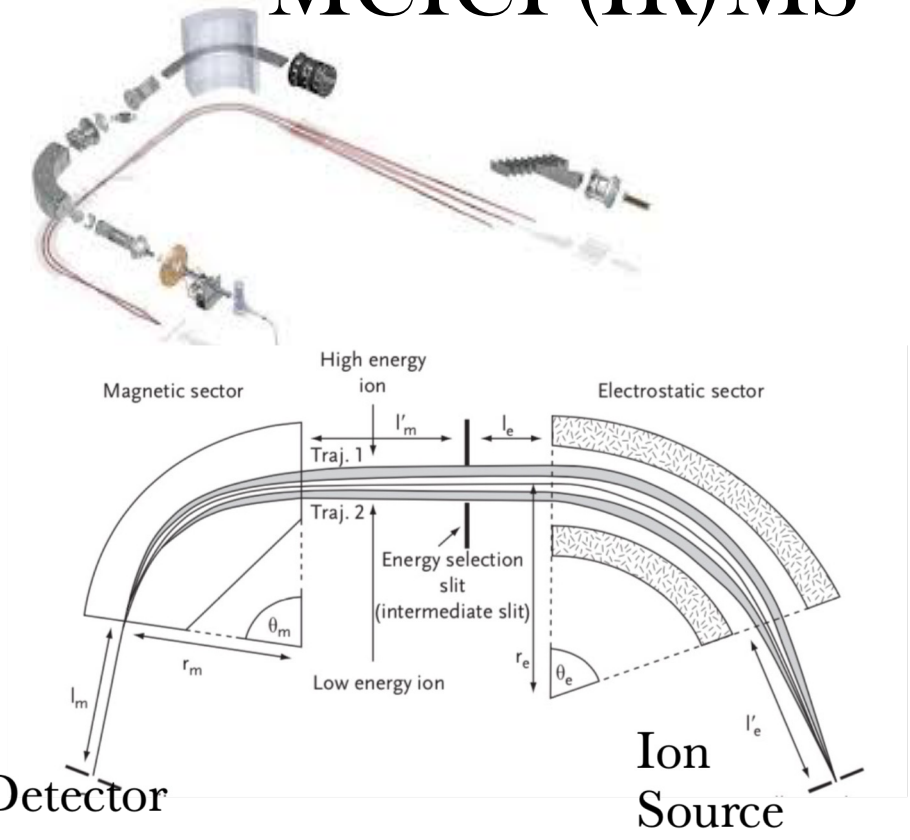
Isotope Ratio (IR) Mass Spectrometry

Stable Isotopes

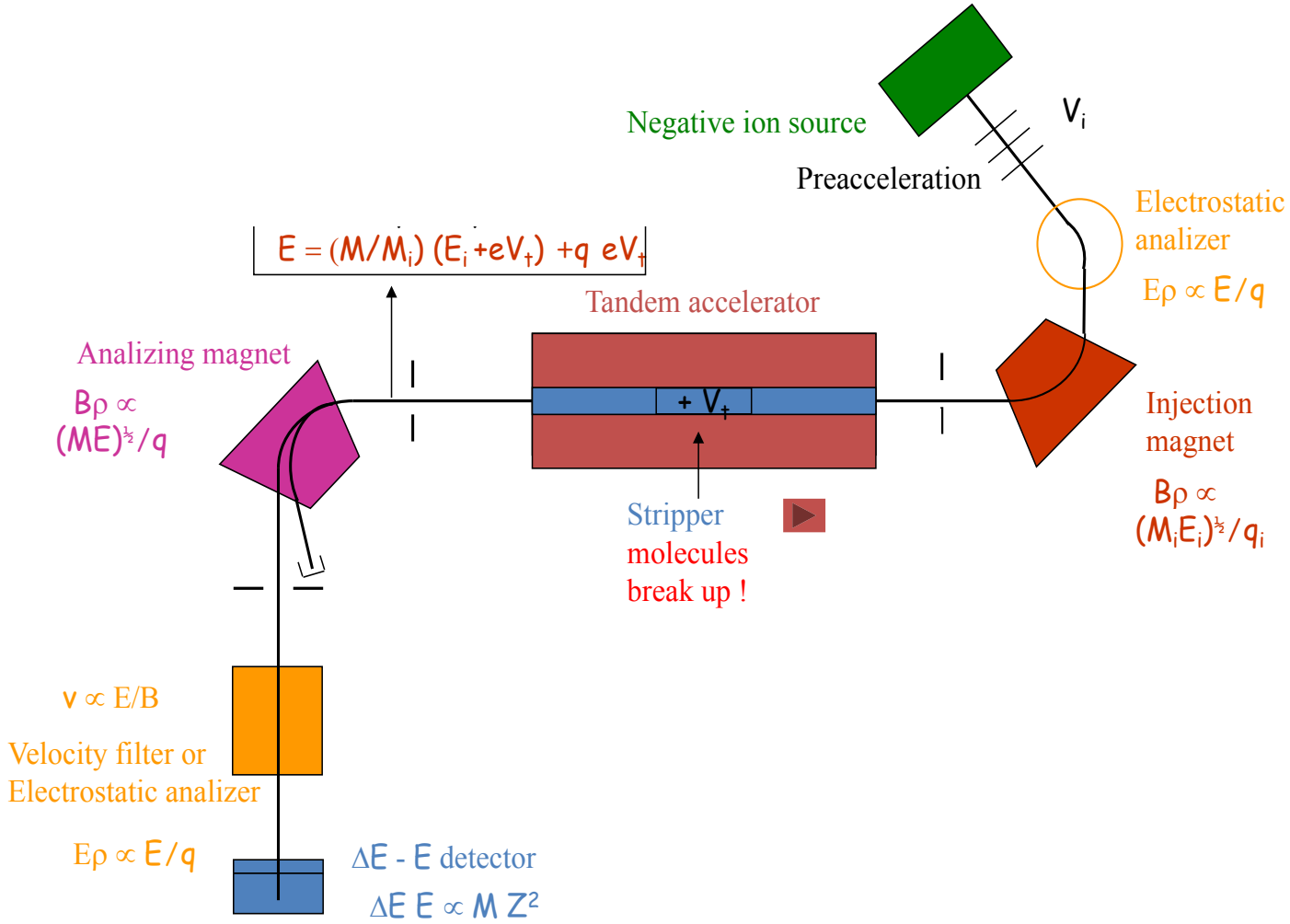
GSIRMS



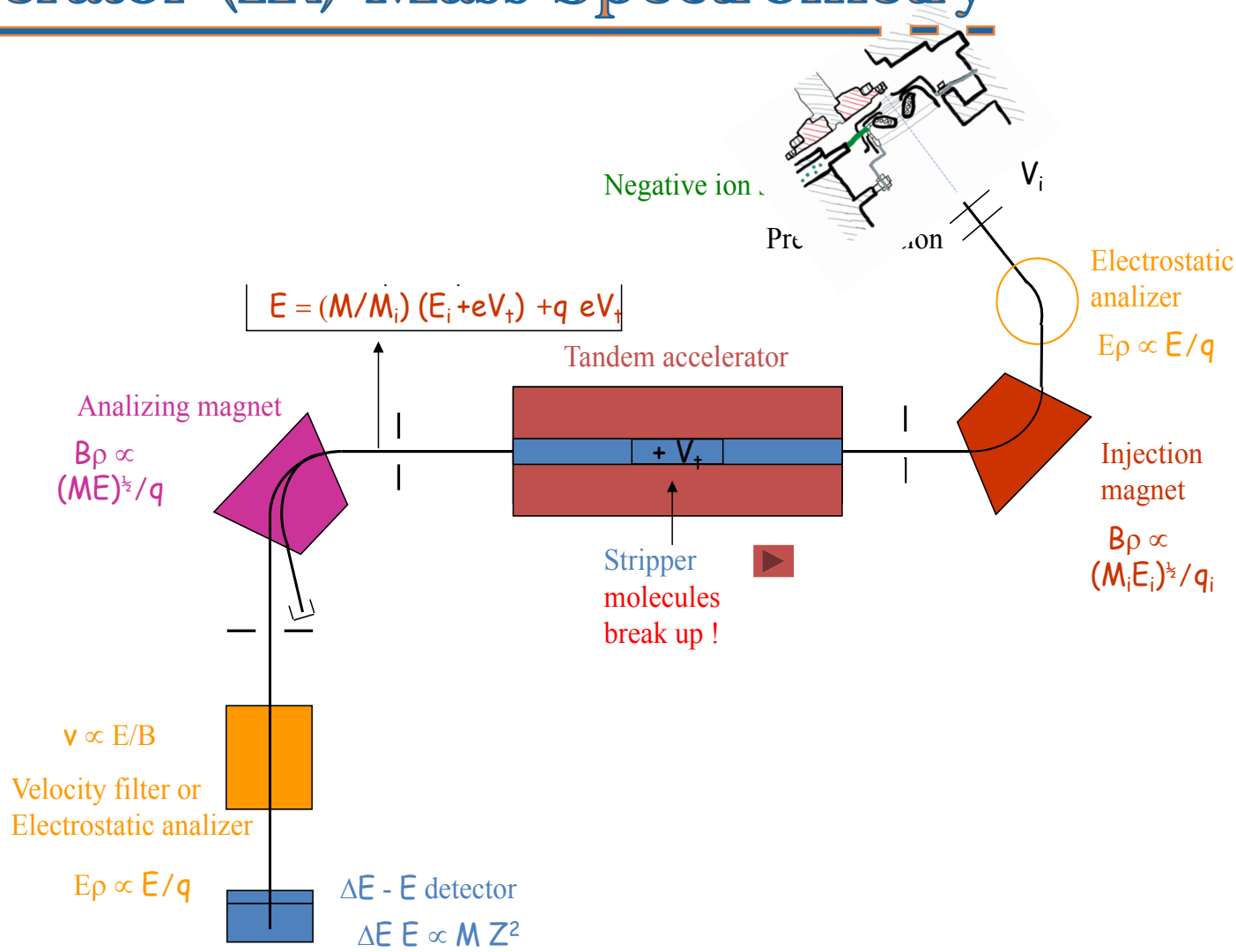
MCICP(IR)MS



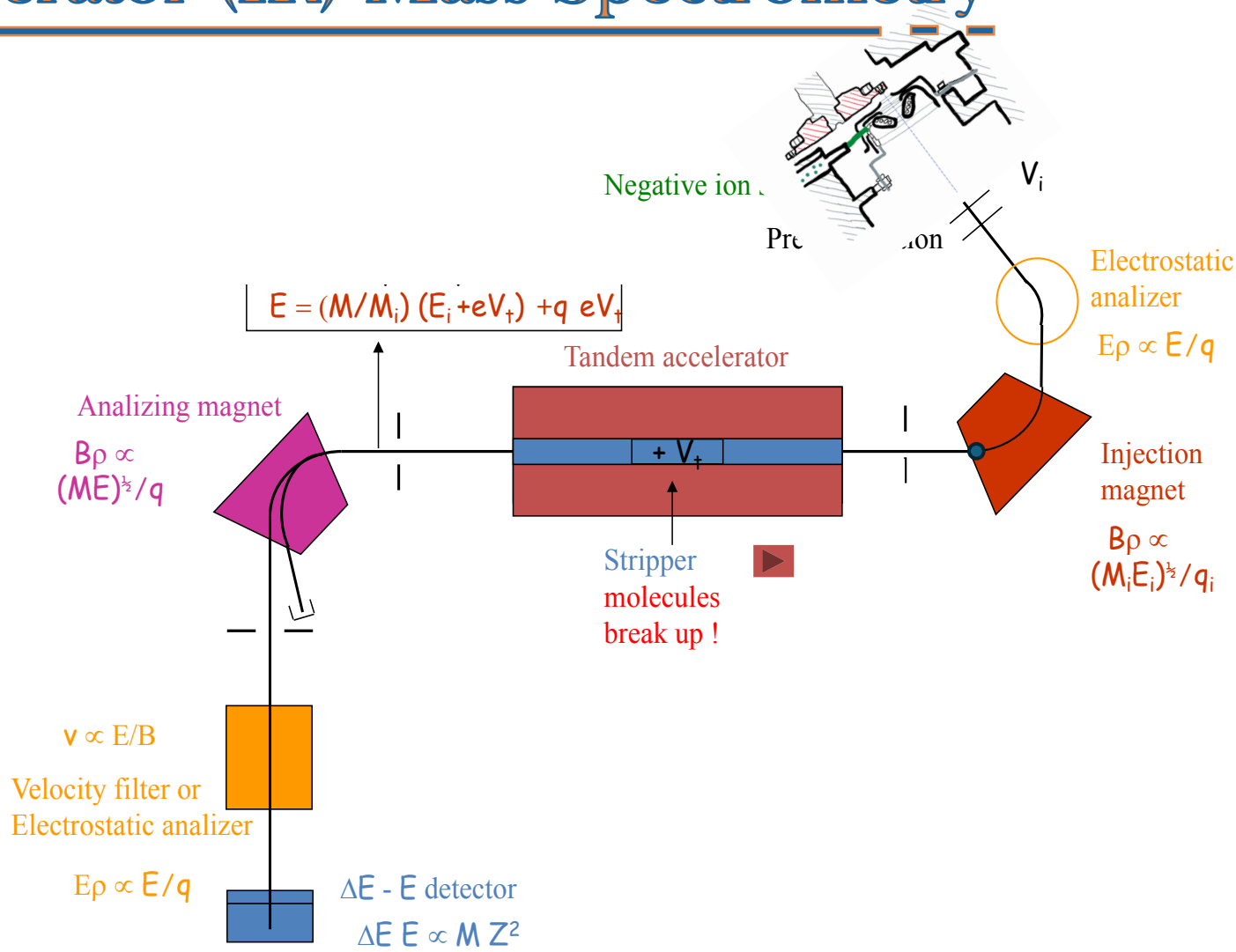
Accelerator (IR) Mass Spectrometry



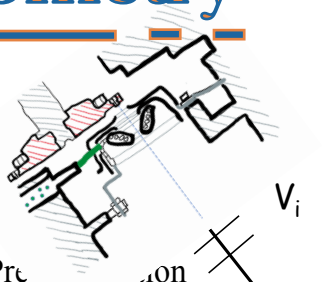
Accelerator (IR) Mass Spectrometry



Accelerator (IR) Mass Spectrometry



Accelerator (IR) Mass Spectrometry



Negative ion

V_i

Pre ion

Electrostatic analizer

$E\rho \propto E/q$

$E = (M/M_i)(E_i + eV_+) + q\,eV_+$

Tandem accelerator

Analizing magnet

$B\rho \propto (ME)^{1/2}/q$

$+V_+$

Stripper molecules break up !

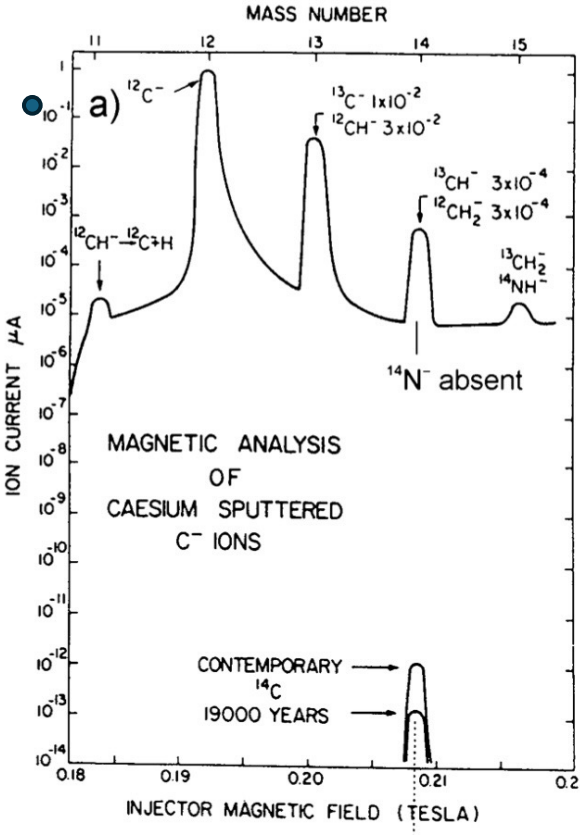
$v \propto E/B$

Velocity filter or Electrostatic analizer

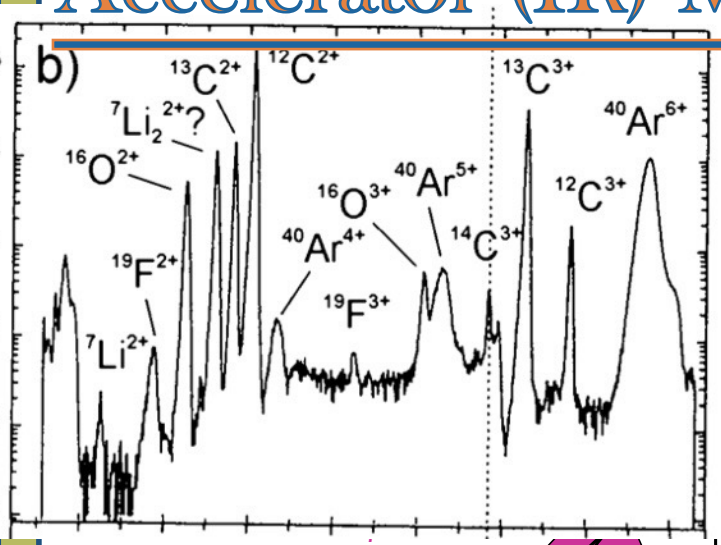
$E\rho \propto E/q$

ΔE - E detector

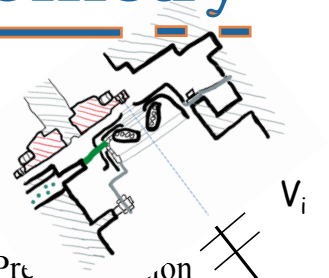
$\Delta E\, E \propto M Z^2$



Accelerator (IR) Mass Spectrometry



$(ME)^{½}/q$



Negative ion

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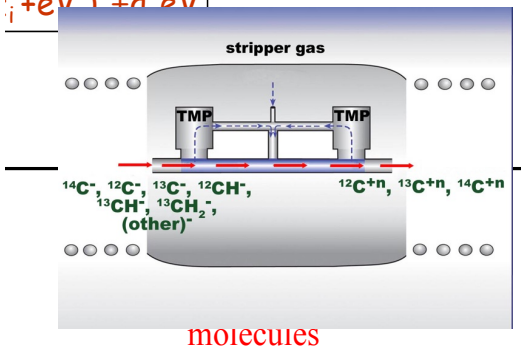
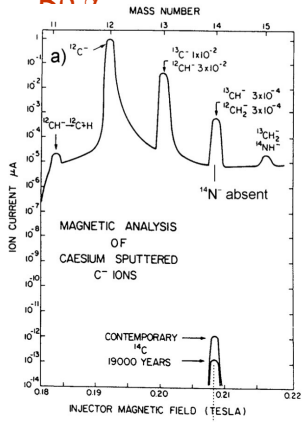


molecules break up !

Injection magnet

$B\rho \propto$



$v \propto E/B$

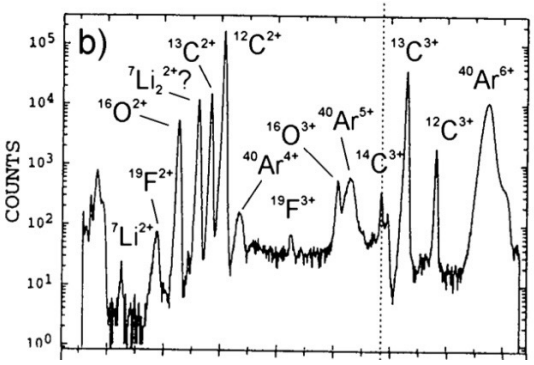
Velocity filter or Electrostatic analizer

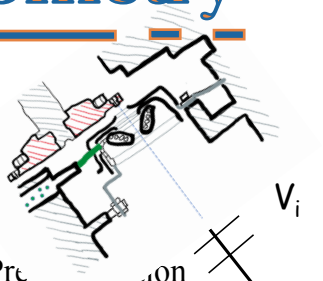
$E\rho \propto E/q$

ΔE - E detector

$\Delta E\, E \propto M Z^2$

Accelerator (IR) Mass Spectrometry



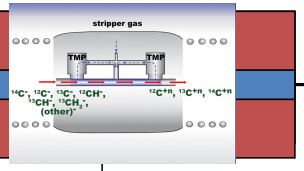


$(M/M_i)(E_i + eV_t) + q\ eV_t$

Electrostatic analizer

$E\rho \propto E/q$

Tandem accelerator



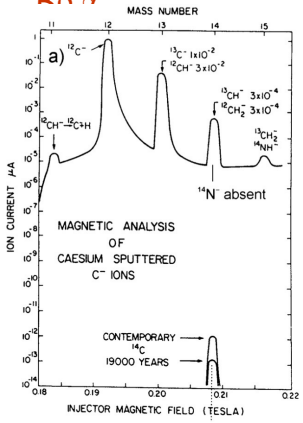
Stripper molecules break up !

Analizing magnet

$B\rho \propto (ME)^{1/2}/q$

Injection magnet

$B\rho \propto$



$v \propto E/B$

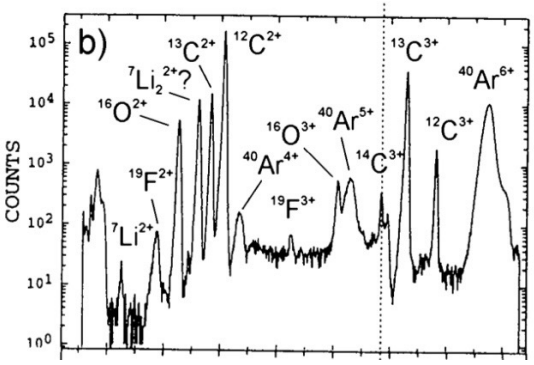
Velocity filter or Electrostatic analizer

$E\rho \propto E/q$

ΔE - E detector

$\Delta E\ E \propto M\ Z^2$

Accelerator (IR) Mass Spectrometry



Negative ion

Pre ion

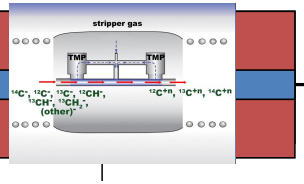
V_i

Electrostatic analizer

$E\rho \propto E/q$

$(M/M_i)(E_i + eV_t) + q\ eV_t$

Tandem accelerator



Analizing magnet

$B\rho \propto (ME)^{1/2}/q$

Injection magnet

$B\rho \propto$

$v \propto E/B$

Velocity filter or Electrostatic analizer

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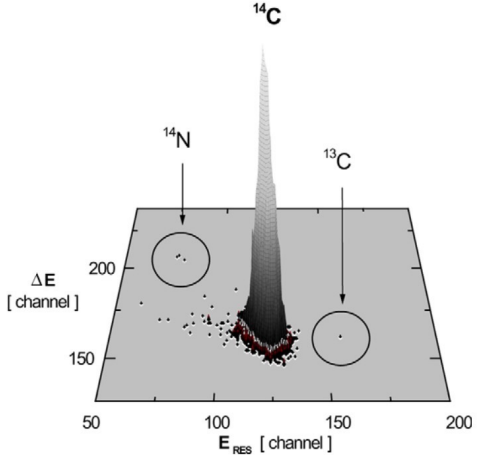
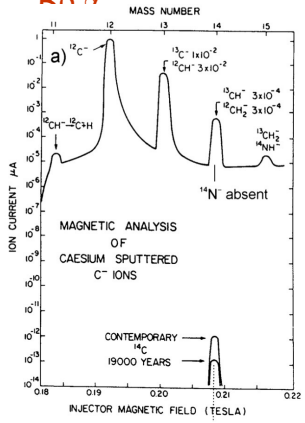
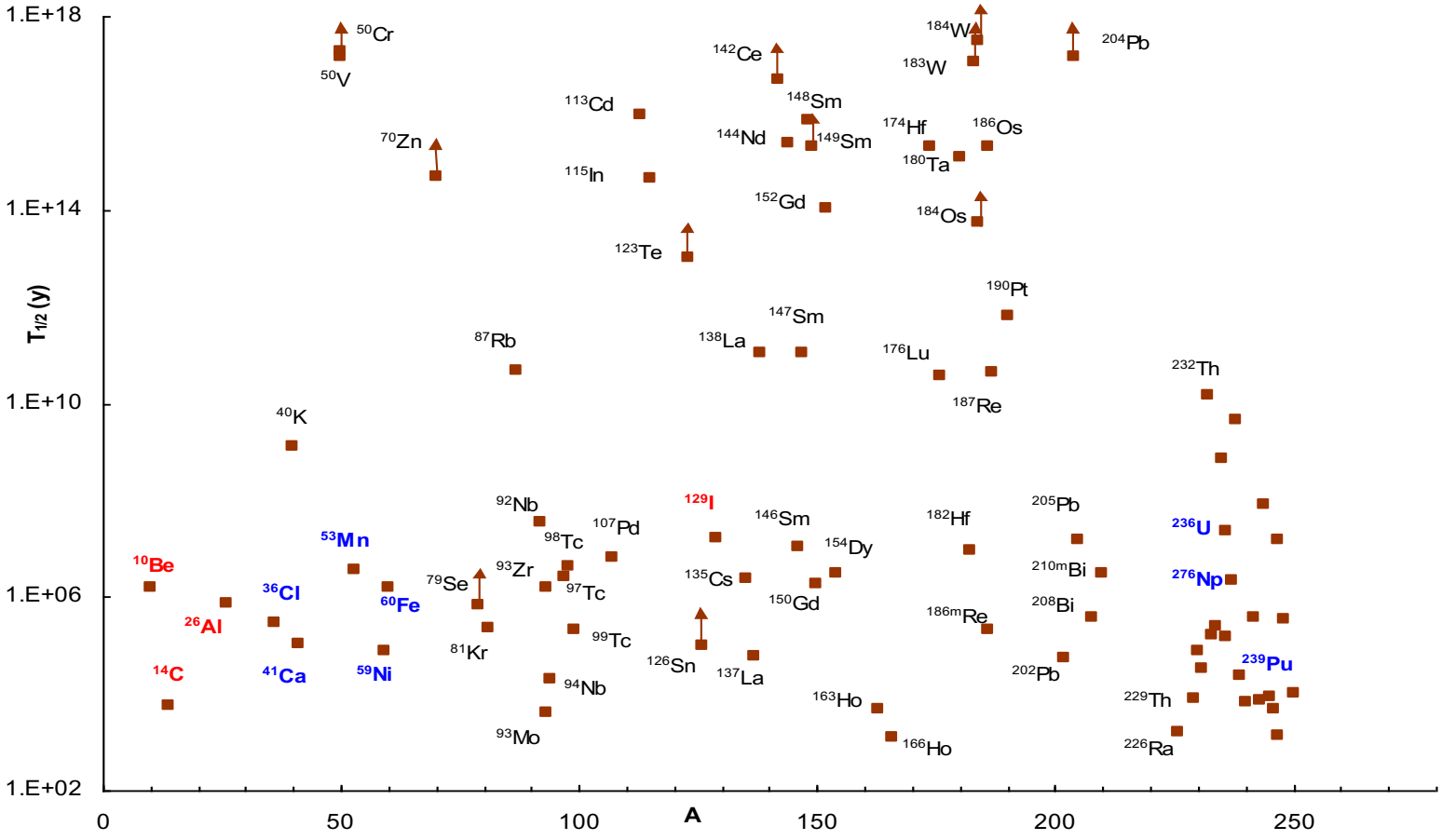
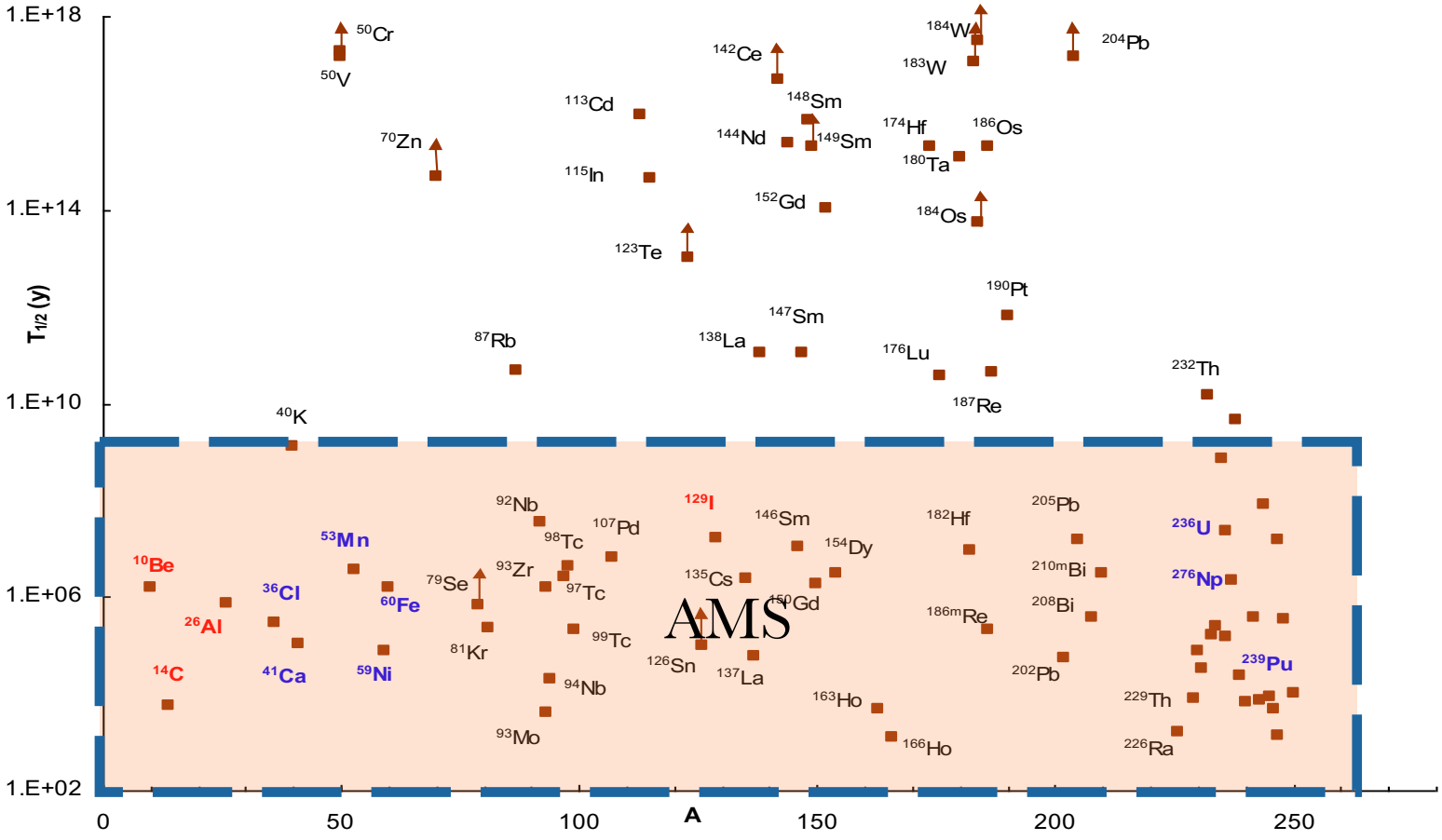




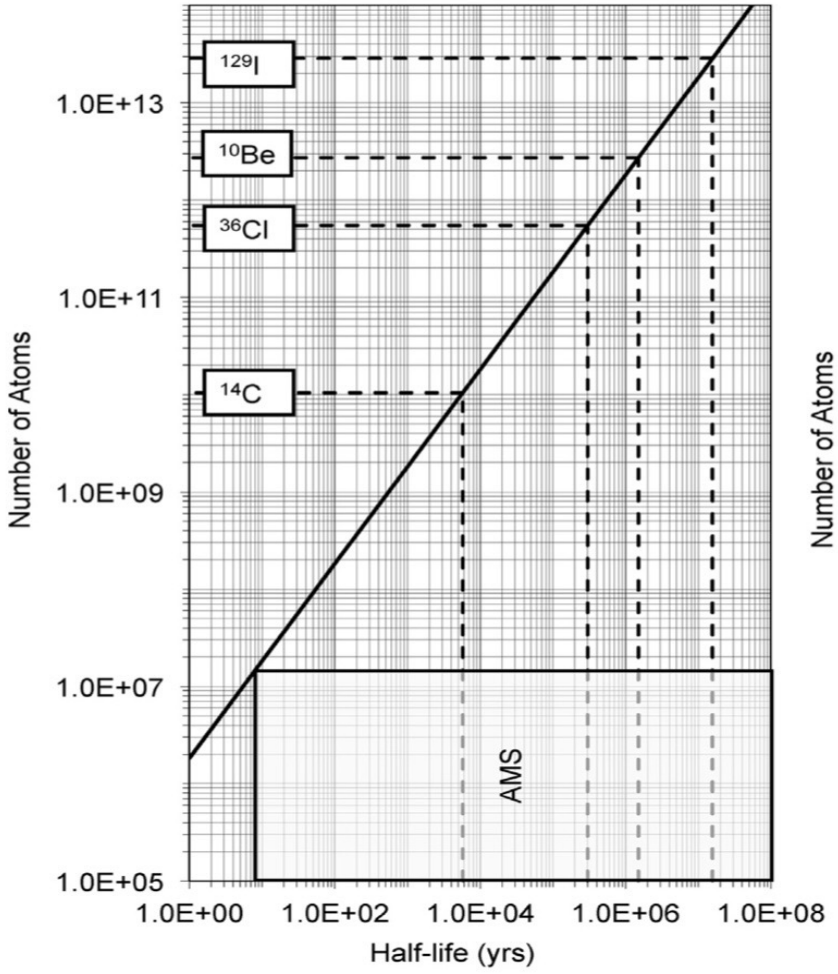
Accelerator (IR) Mass Spectrometry

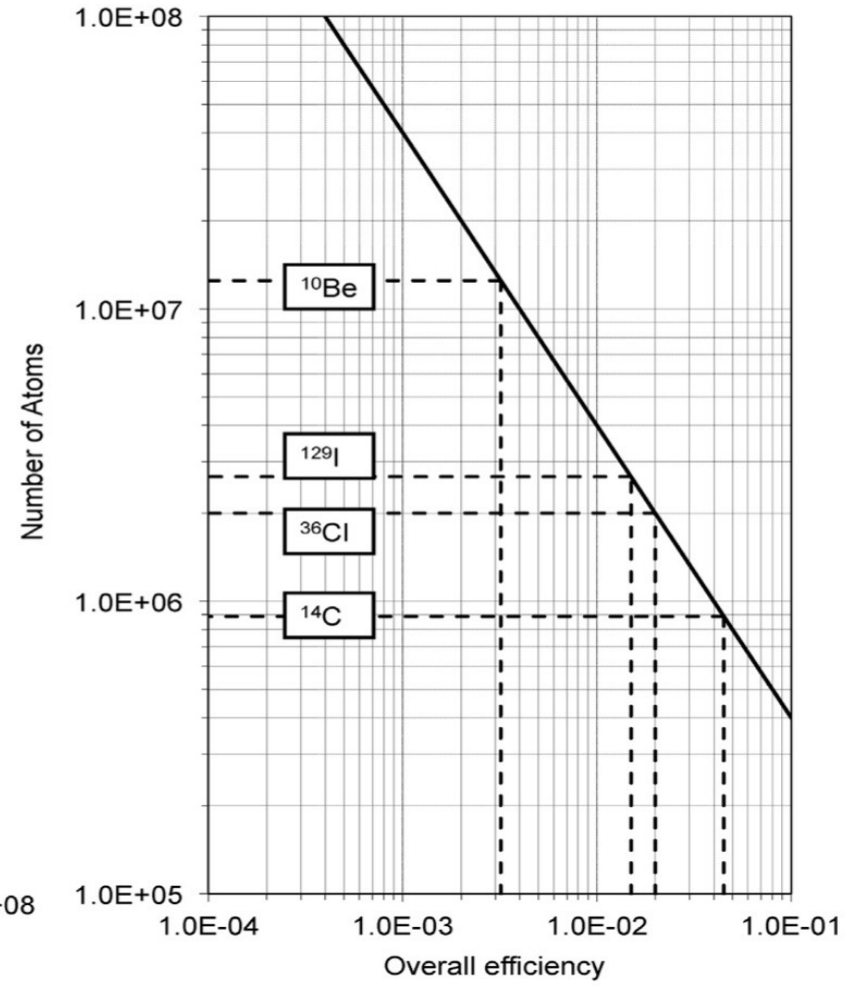


Accelerator (IR) Mass Spectrometry



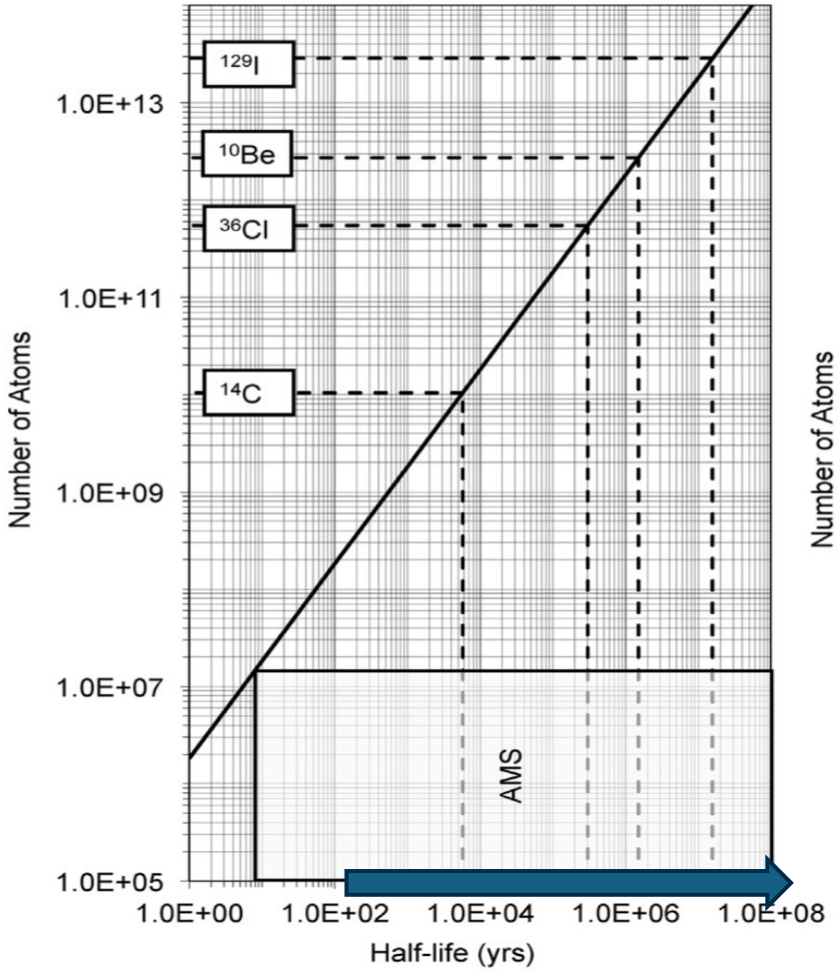
Accelerator (IR) Mass Spectrometry

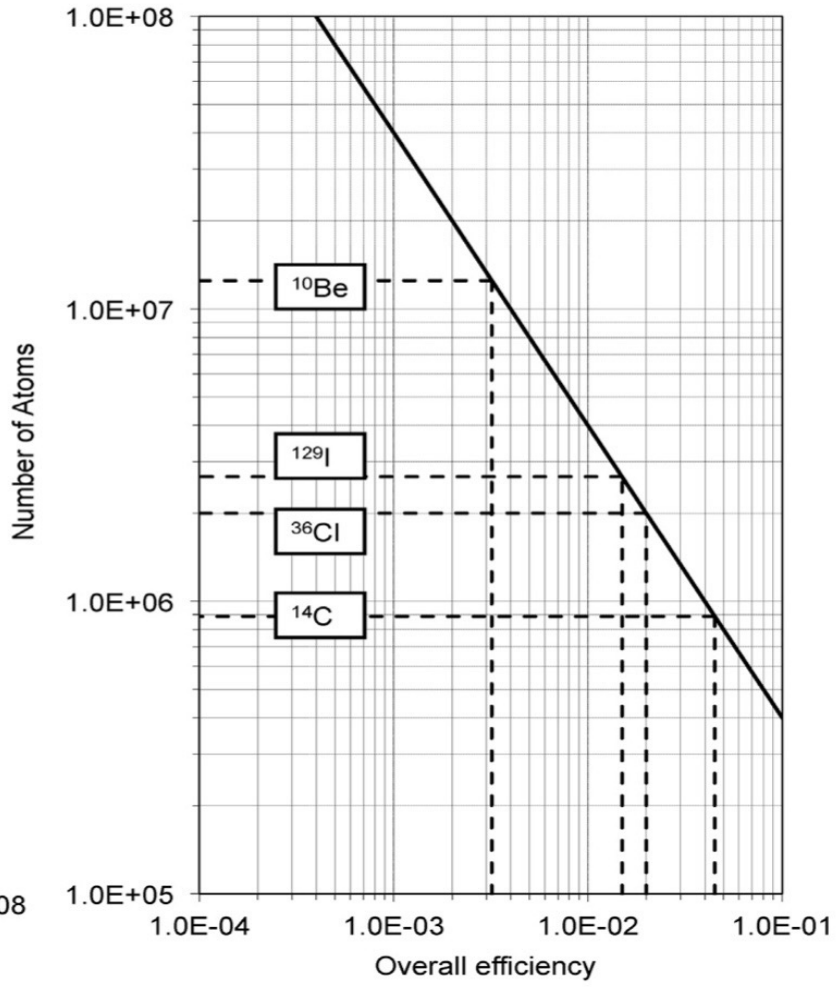




Accelerator (IR) Mass Spectrometry

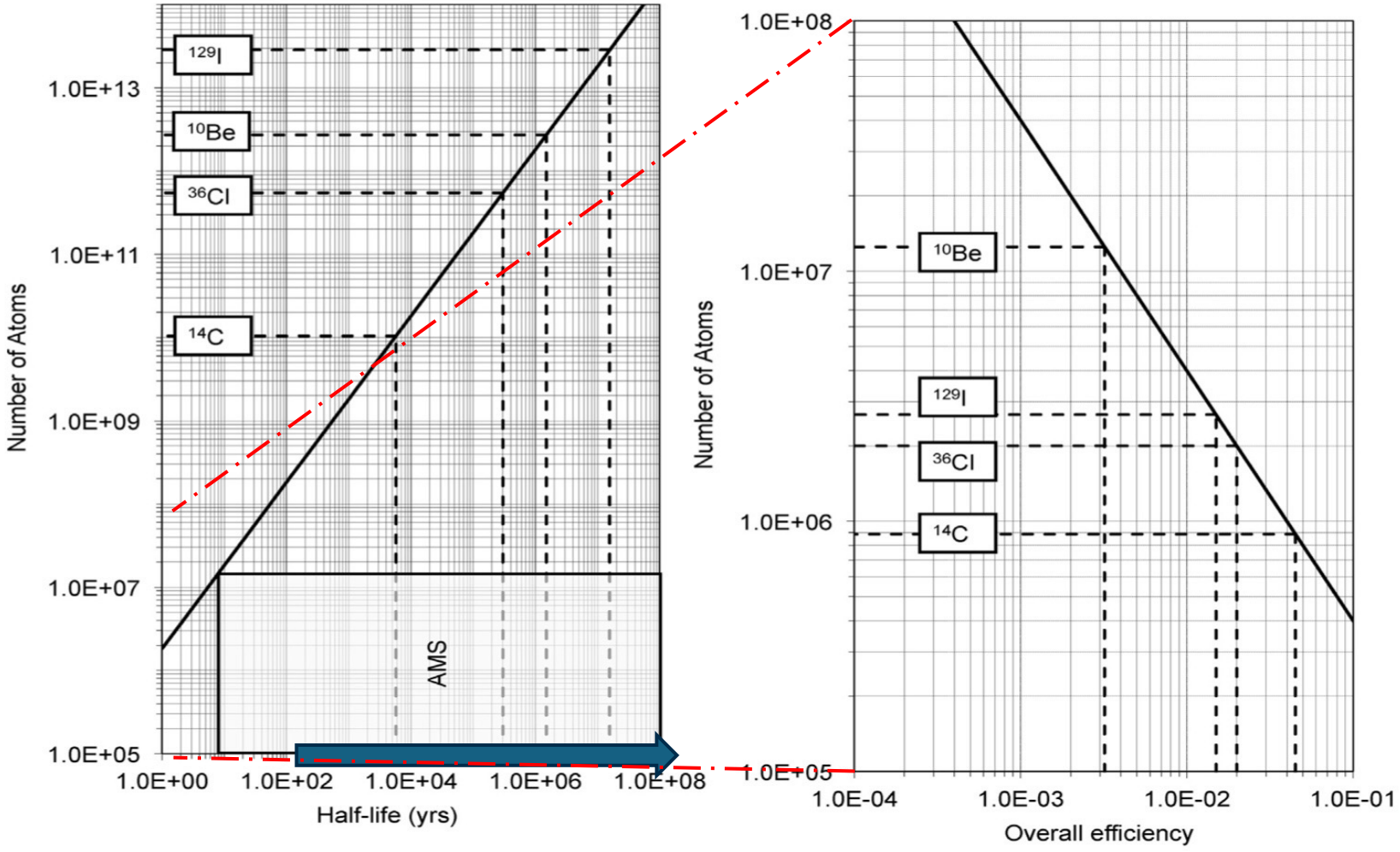
Radiometric





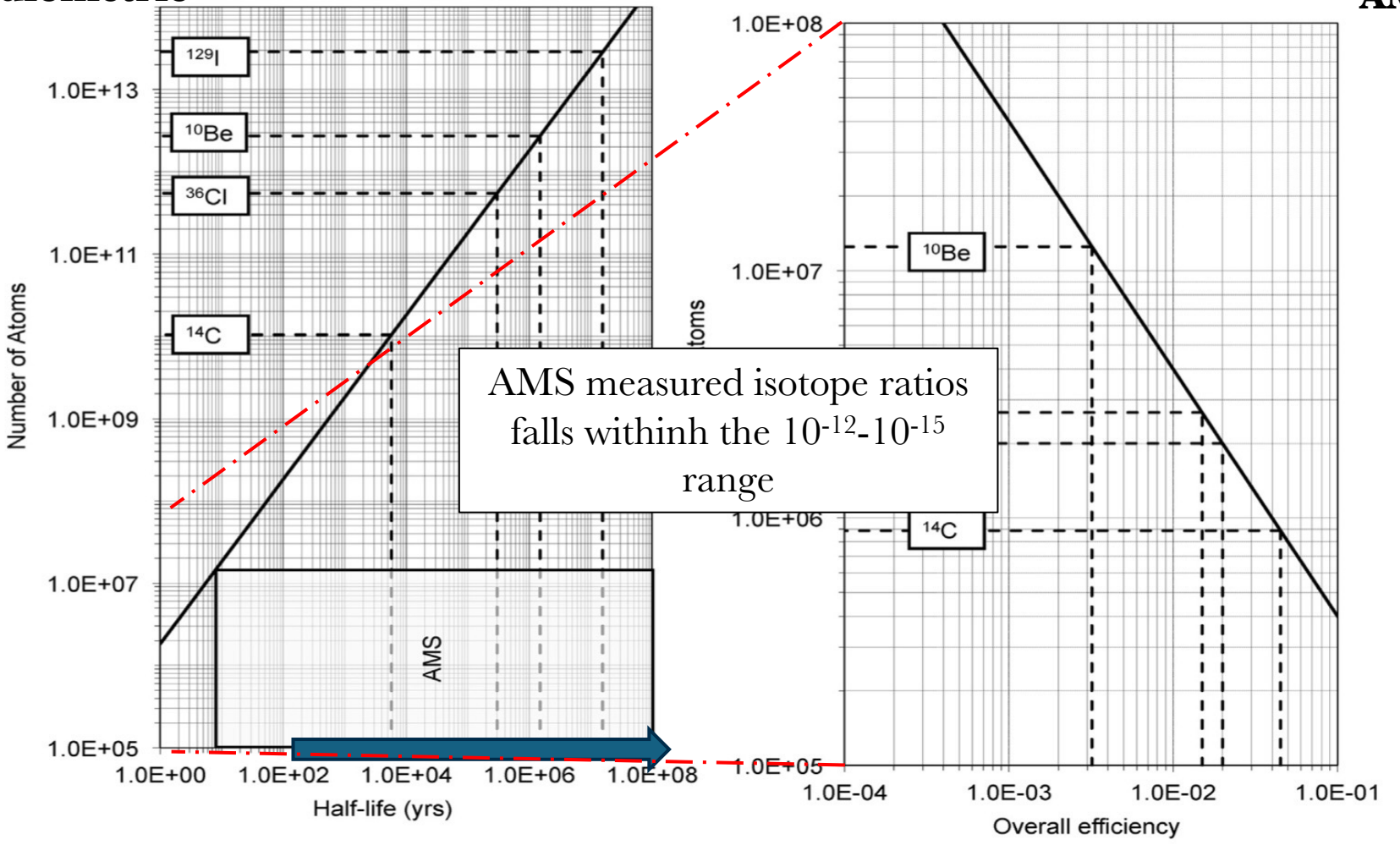
Accelerator (IR) Mass Spectrometry

Radiometric

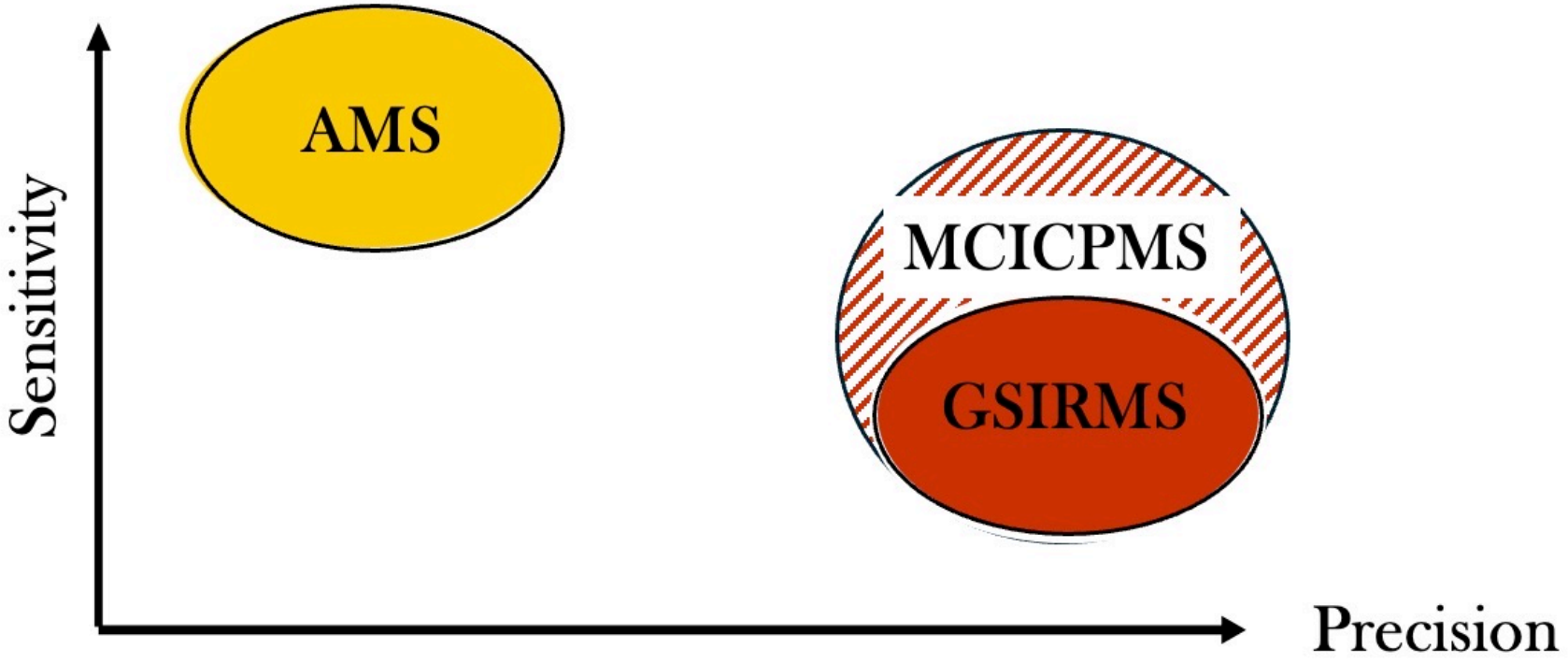


Accelerator (IR) Mass Spectrometry

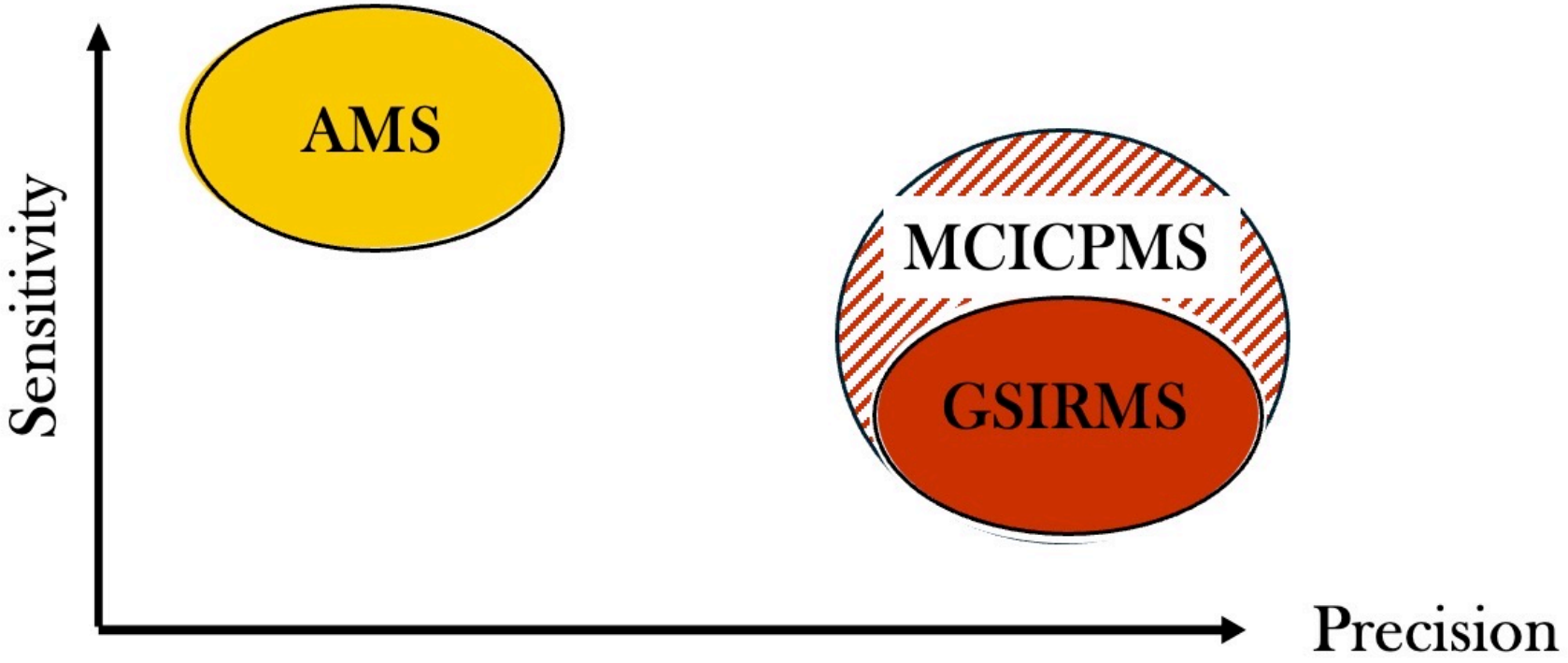
Radiometric **AMS**



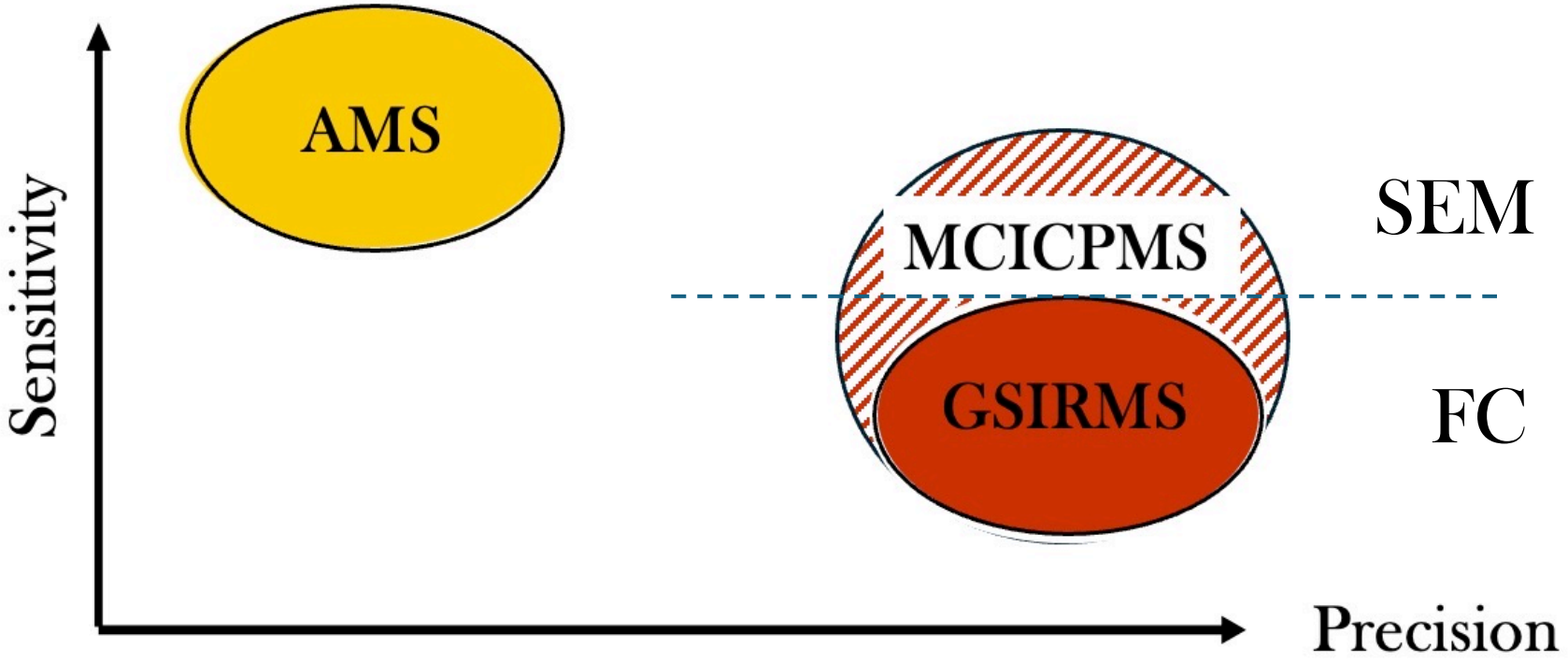
IR Mass Spectrometry comparison



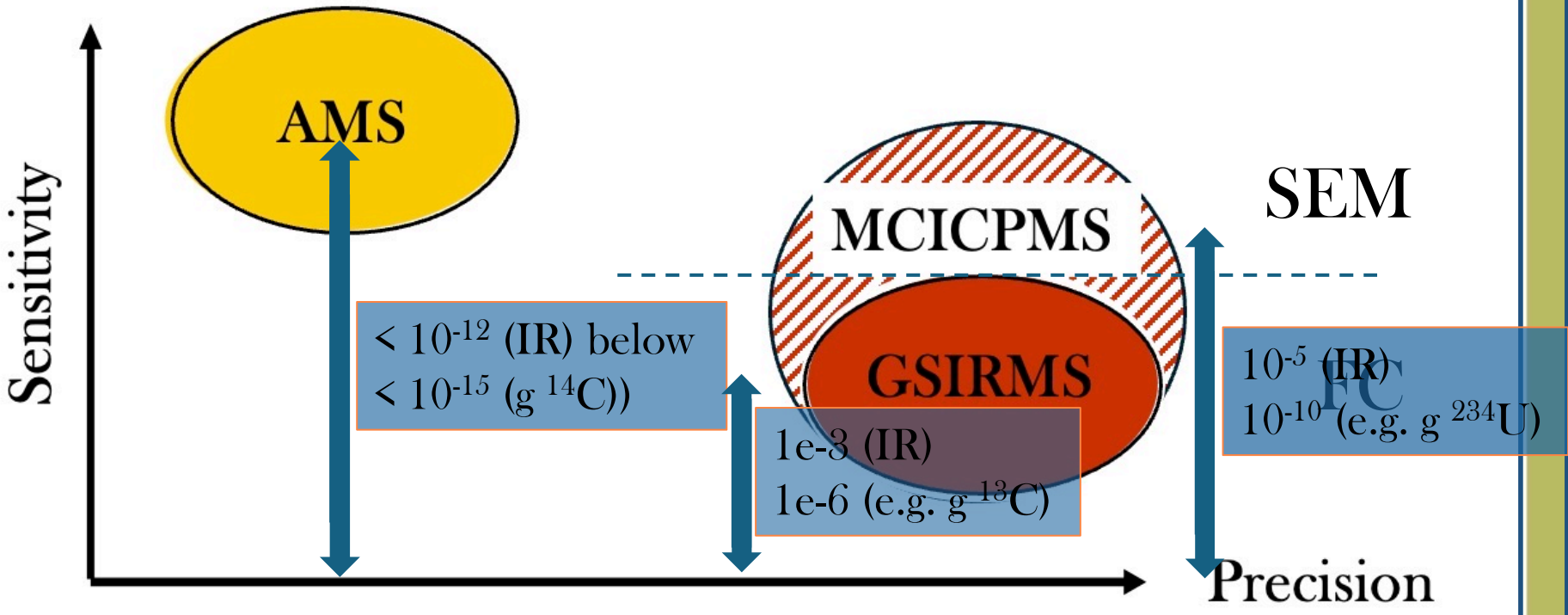
IR Mass Spectrometry comparison



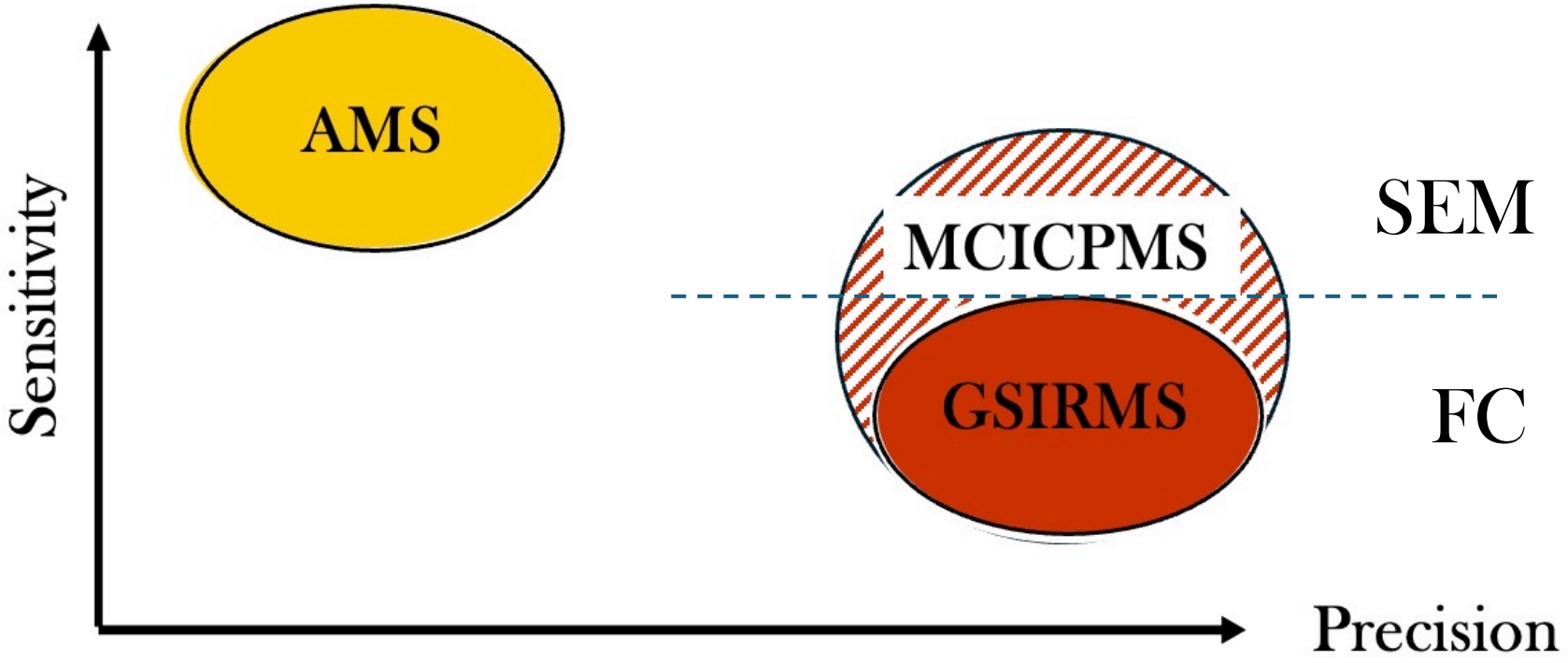
IR Mass Spectrometry comparison



IR Mass Spectrometry comparison



IR Mass Spectrometry comparison



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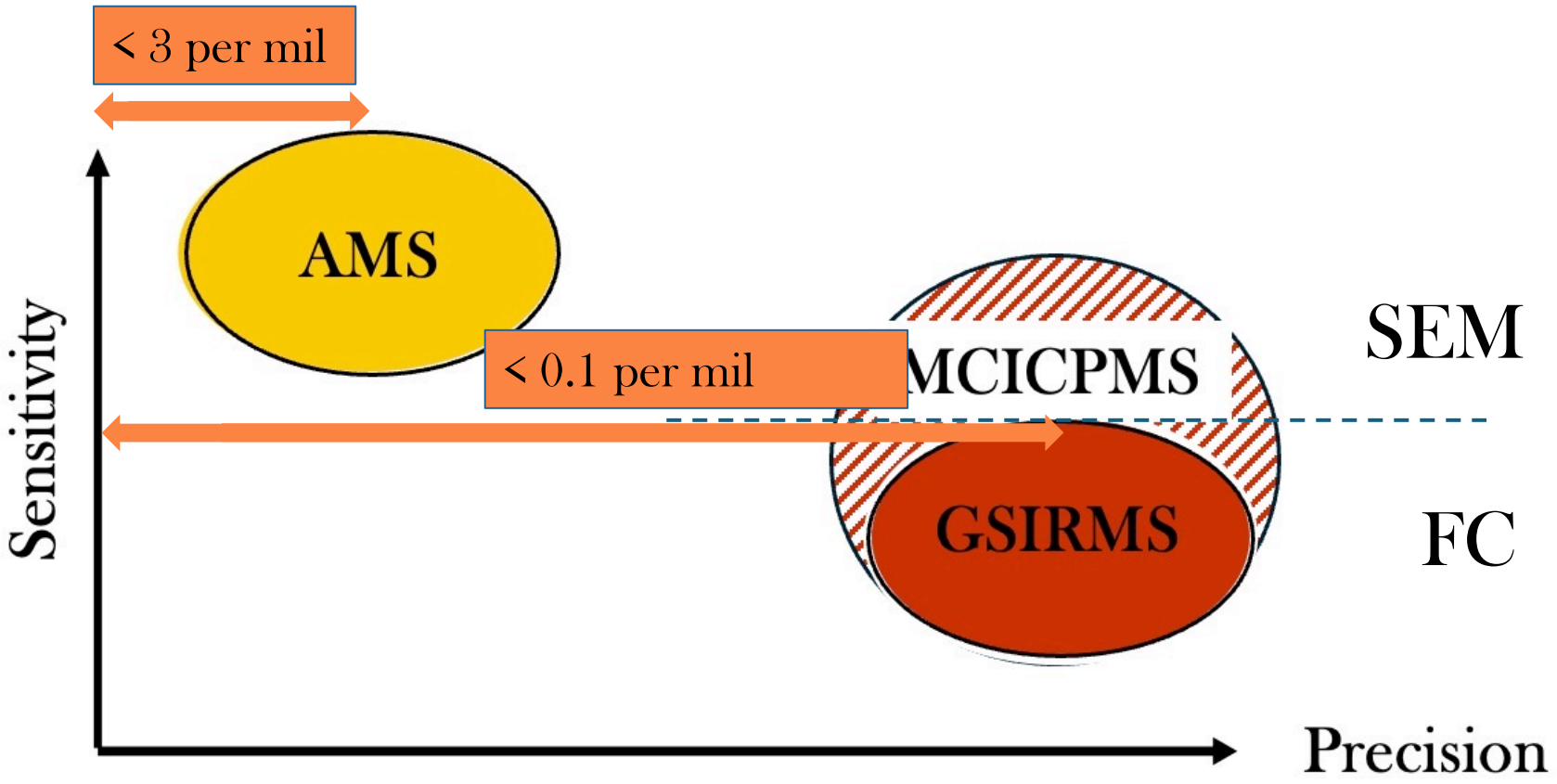
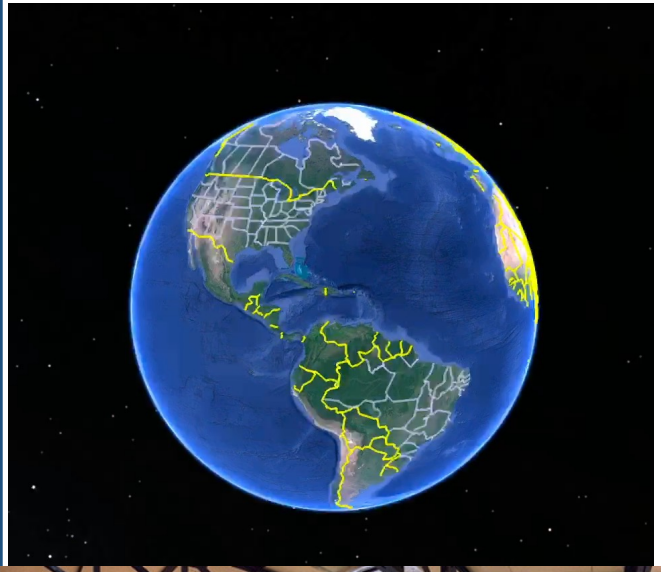
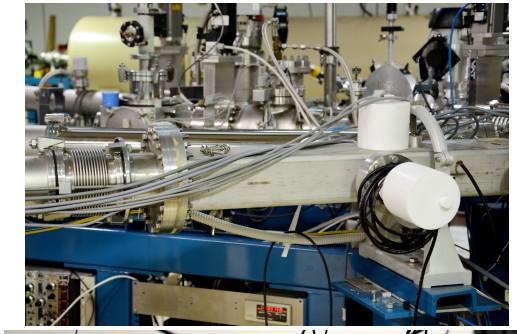
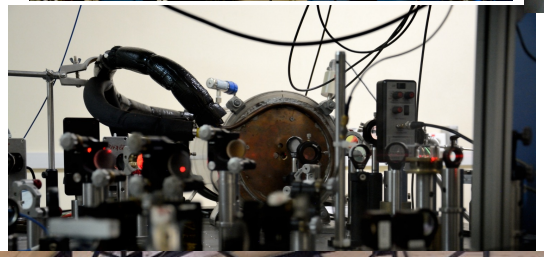


Centre for Isotope Research on Cultural and Environmental heritage







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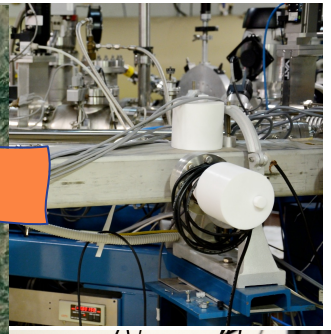

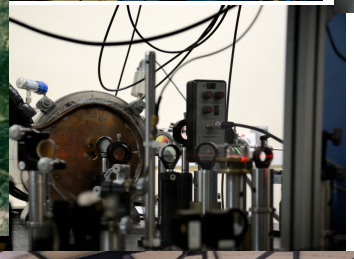

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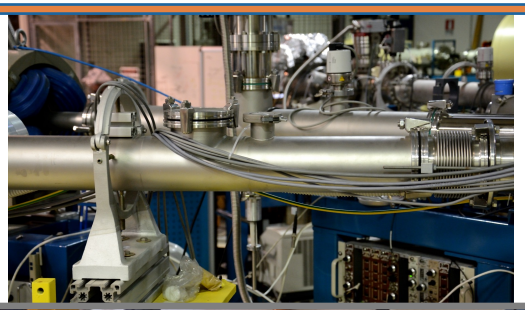
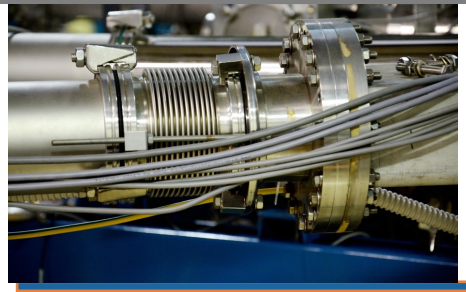
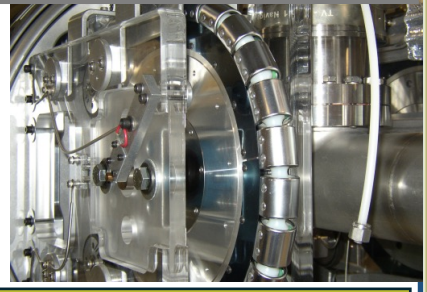
Accelerator Mass Spectrometry Lab

AMS Lab

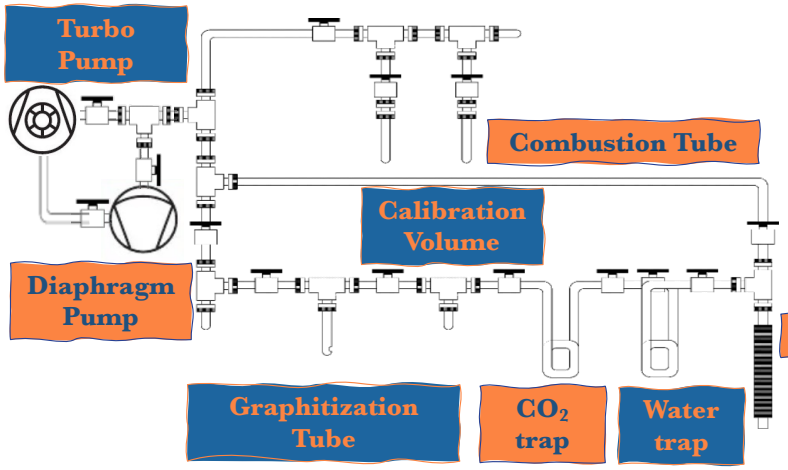


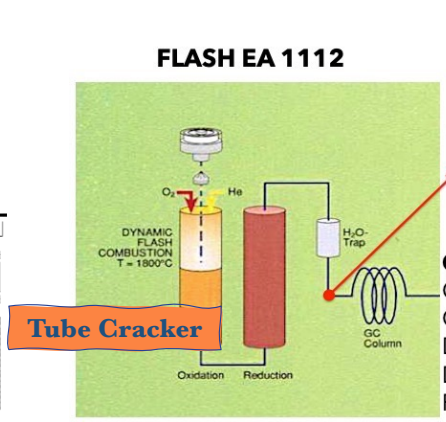


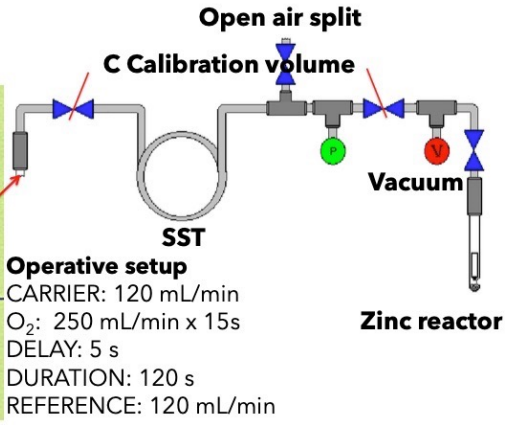


^{14}C Sample Preparation Lab

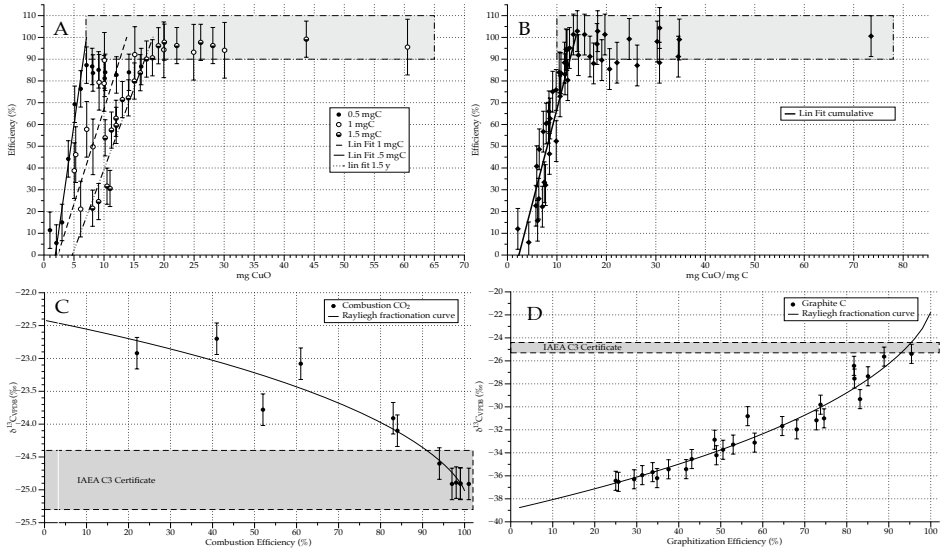
Sample Preparation Lab

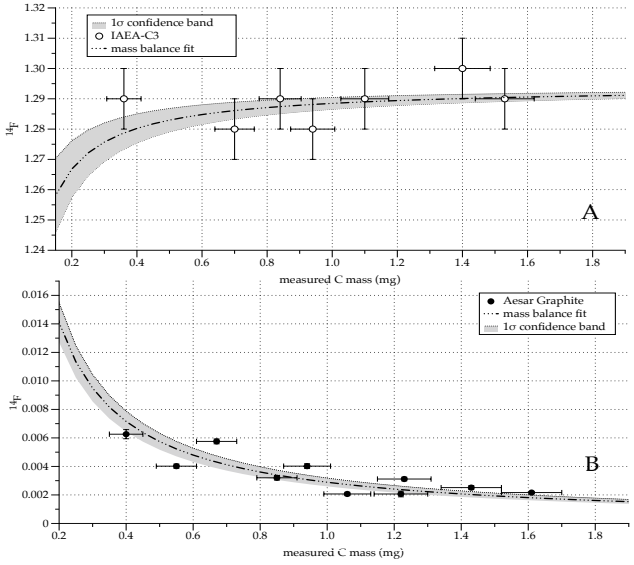






Operative setup
CARRIER: 120 mL/min
O_2: 250 mL/min x 15s
DELAY: 5 s
DURATION: 120 s
REFERENCE: 120 mL/min





Applications A(IR)MS

^{14}C Chronology

Nuclear safeguard by U and Pu isotope ratios

Biobased

Environmental pollution

Nuclear Astrophysics

^{14}C Anomalies studies

Particulate Matter speciation

Anthropogenic CO_2 Flux quantification

Materials Science

Forensics

IRMS

(GS)IRMS Lab


Thermo Fisher Sci. DELTA V IRMS Dual Inlet
Thermo TC/EA
GC-C/TC Unit
PAL AutoSampler
EA-TCEA
ConFlo IV
EA Flash™ 1112
Gas Bench II
ConFlo III
ConFlo II
Thermo Fisher Sci. DELTA V IRMS
Thermo Finnigan DELTAplus IRMS with Dual Inlet

Applications (GS)IRMS

Environmental pollution – Water resources

- Contamination of water resources from landfill leachate
- Nitrate (NO_3^-) contamination of groundwater and superficial water bodies

Environmental pollution – Particulate Matter

Food Traceability

Biogeochemical Cycles

- Carbon Cycle
- Water Cycle

Materials Science

Archaeometry

Applications: Stable and Radioactive Isotopes

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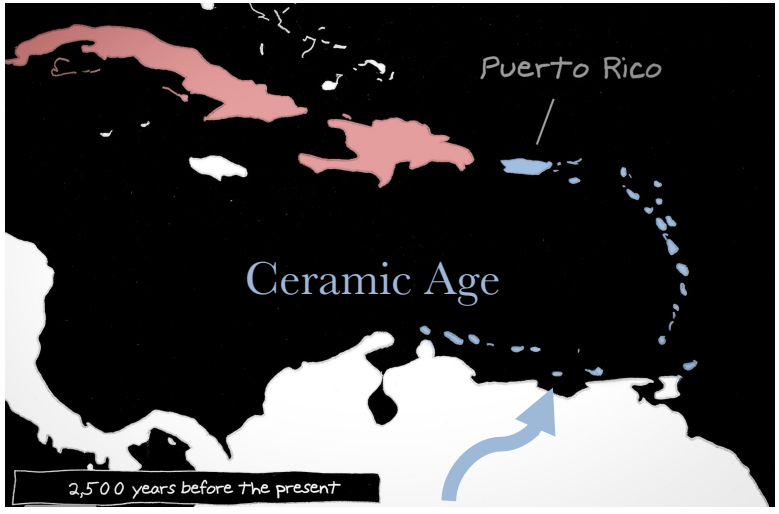

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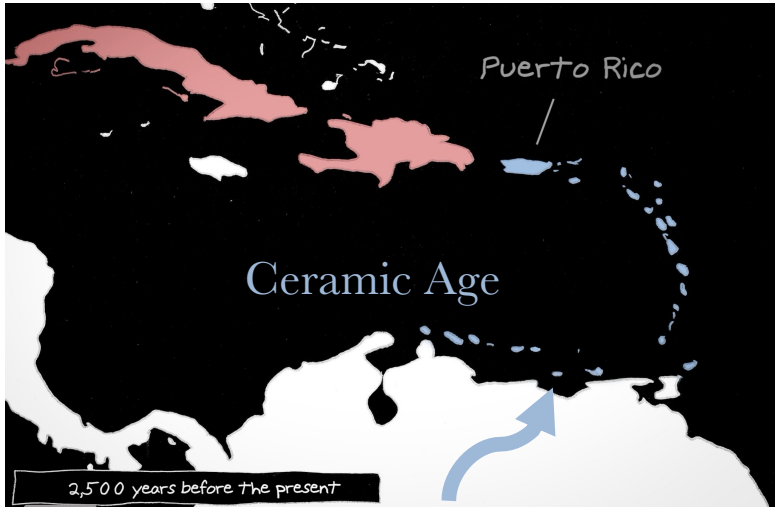

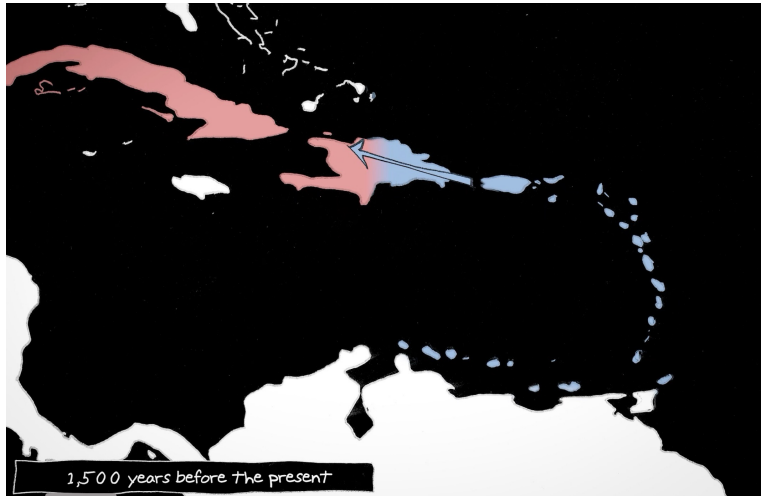

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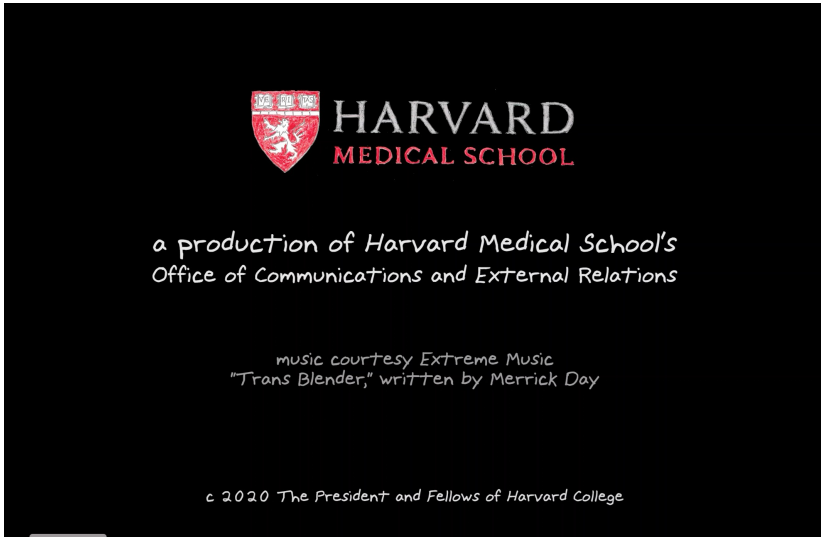

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The New York Times

MATTER

Ancient DNA Shows Humans Settled Caribbean in 2 Distinct Waves

Millions of people living on the islands today inherited genes from the people who made them home before Europeans arrived.

Taíno ceramic vessels from eastern Dominican Republic, circa A.D. 1400. Menno Hoogland/Leiden University

By Carl Zimmer

The New York Times

Opinion

Ancient DNA Is Changing How We Think About the Caribbean

New research delivers surprising findings about Indigenous people in the region before contact with Europeans.

By David Reich and Orlando Patterson
Dr. Reich is a geneticist at Harvard who specializes in the study of ancient DNA. Dr. Patterson is a sociologist at Harvard with expertise in the Caribbean.

Dec. 23, 2020

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NATIONAL GEOGRAPHIC

Caribbean traders approach an island in the Bahamas, part of an ancient exchange network that knit the islands together before the arrival of the Spanish.
PAINTING BY MERALD CLARK, STONE INTERCHANGES IN THE BAHAMA ARCHIPELAGO

HISTORY & CULTURE | NEWS

Invaders nearly wiped out Caribbean's first people long before Spanish came, DNA reveals

New genetic data from ancient bones suggests a wave of South American seafarers wreaked havoc on Caribbean islanders.

BY ANDREW LAWLER

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Ancient DNA retells story of Caribbean's first people, with a few plot twists

by Natalie Van Hoose, Florida Museum of Natural History

Archaeological research and ancient DNA technology can work hand in hand to illuminate p...

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What Ancient DNA Reveals About the First People to Populate the Caribbean

New study suggests a group of migrants almost totally replaced the islands' original population

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«Così si è formata la gente dei Caraibi» Due docenti alla scoperta delle origini

Terrasi e Marzaioli (sotto) hanno condotto una indagine sui Caraibi

ALLA VANVITELLI

Enzo Battarra

La fisica e la matematica unite per capire le origini delle popolazioni. È quanto hanno fatto all'università Vanvitelli Fabio Marzaioli, professore associato di Fisica Applicata, e Filippo Terrasi, professore emerito presso il Dipartimento di Matematica e Fisica.

I risultati di un loro lavoro sono stati pubblicati su «Nature», una delle più antiche e importanti riviste scientifiche esistenti, forse in assoluto quella considerata di maggior prestigio nell'ambito della comunità scientifica internazionale. Giunge così un'altra notevole soddisfazione per l'ateneo casertano.

I due docenti che fanno ricerca all'ombra della Reggia sono inseriti in un team internazionale di genetisti, archeologi, antropologi, curatori di musei e fisici.

Questo gruppo ha condotto il più ampio studio finora effettuato sul Dna. Il team ha fatto luce sulla storia e sulla preistoria dei Caraibi. Utilizzando un nuovo metodo, gli scienziati confermano che le popolazioni dei Caraibi hanno origini indigene e che quindi provengono da popolazioni antecedenti al contatto con gli europei. Fabio Marzaioli e Filippo Terrasi hanno contribuito all'analisi radiocarbonica e al la-

MARZAIOLI E TERRA... CON LA ... E LA MA... STUDIAN... DELLA P...

nas, Cuba, Repubblica Dominicana, Haiti, Porto Rico, Guadalupa, Santa Lucia, Curaçao e Venezuela.

Le analisi hanno riguardato infanti il corredo genetico delle persone che vissero nei Caraibi tra circa 3.100 e 400 anni prima del presente, sulla base di 45 date radiocarboniche appositamente prodotte. I dati hanno di fatto risolto diversi dibattiti archeologici e antropologici, evidenzian-

La ricostruzione cronologica degli eventi con il carbonio-14 ha richiesto un'analisi dettagliata

Vanvitelli MAGAZINE

RASSEGNA STAMPA

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Credit: Long Journey's End. (c) Merald Clark, for SIBA. Stone Interchanges in the Bahama Archipelago

21 GENNAIO 2021

Il DNA antico fa luce su storia e preistoria dei Caraibi. Alla Vanvitelli lo studio sul radiocarbonio pubblicato su Nature

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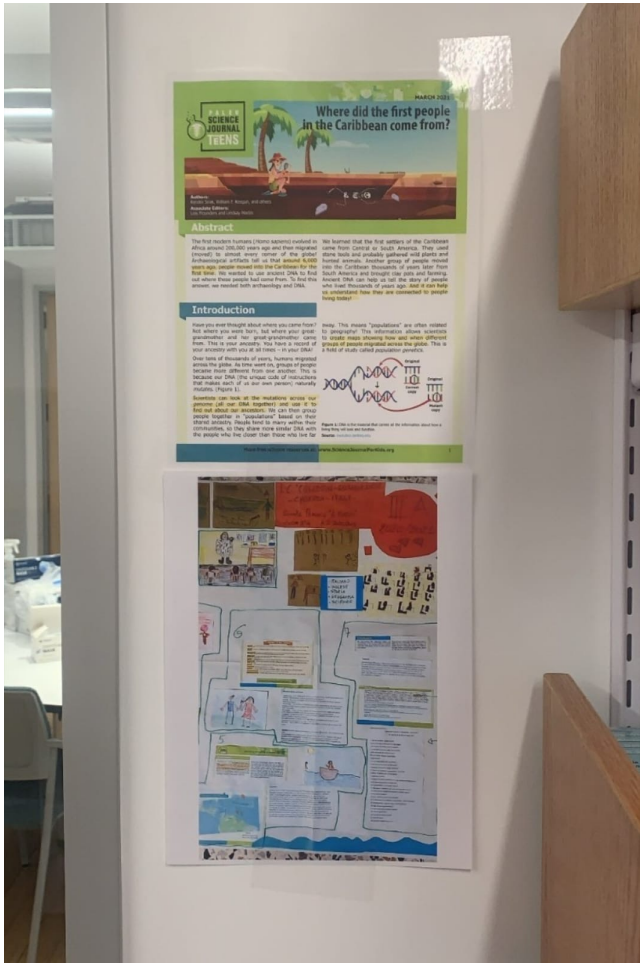

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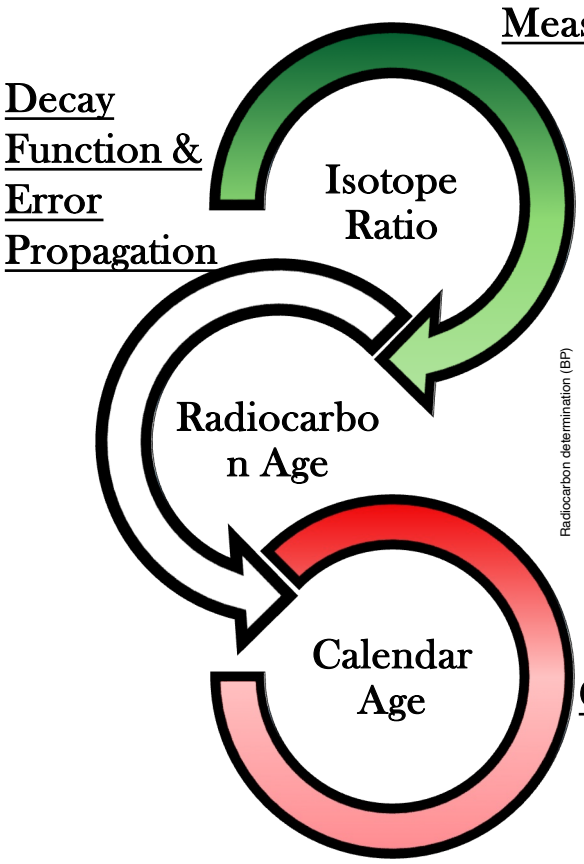
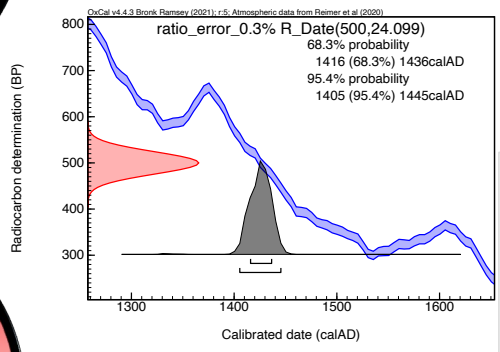
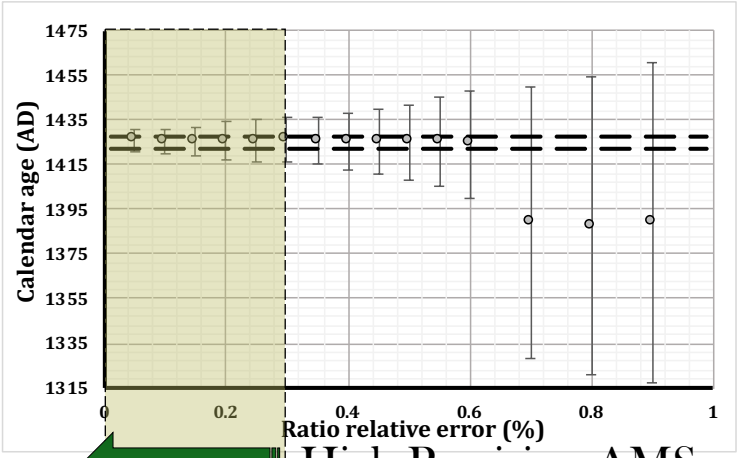
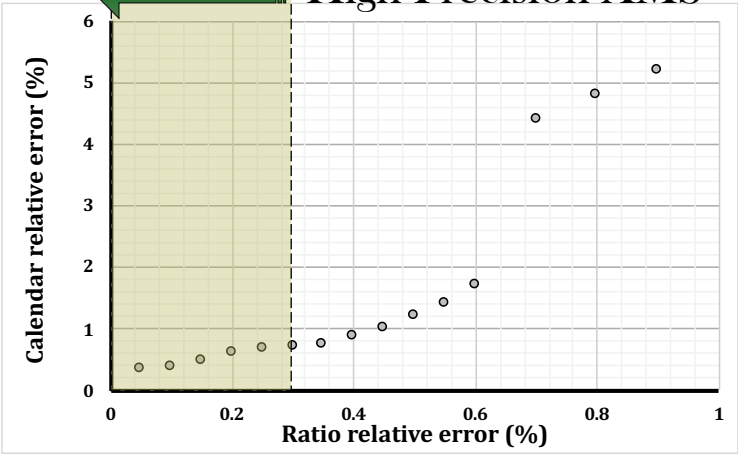






High Precision AMS



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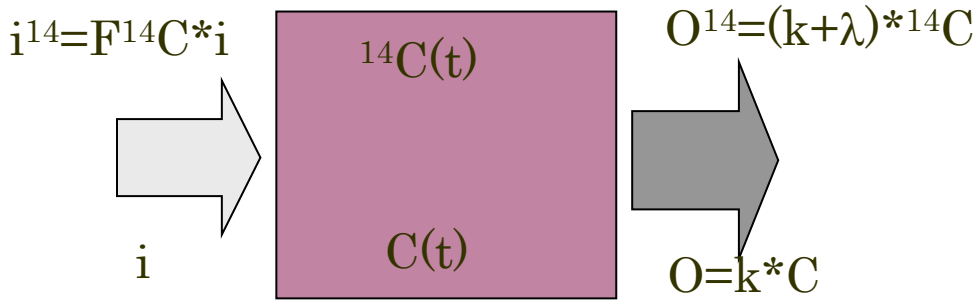
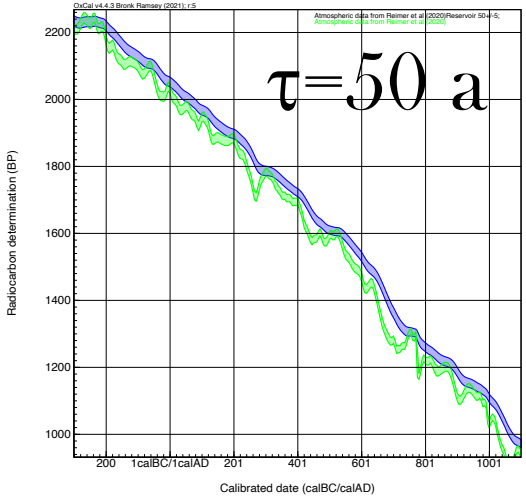
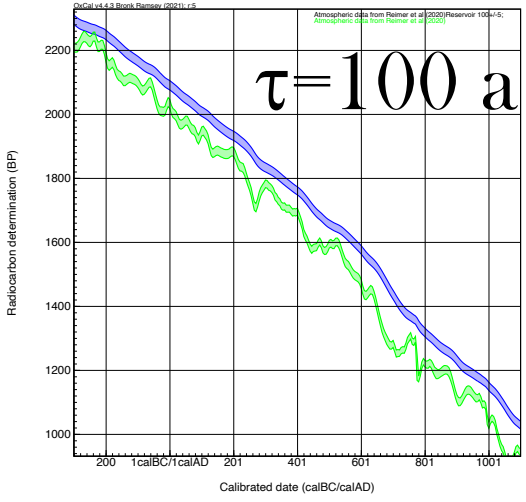
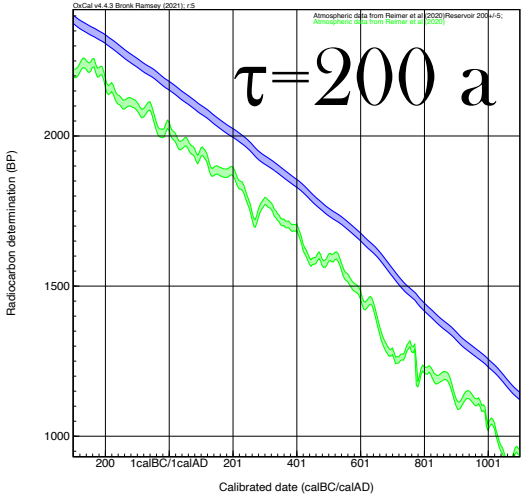
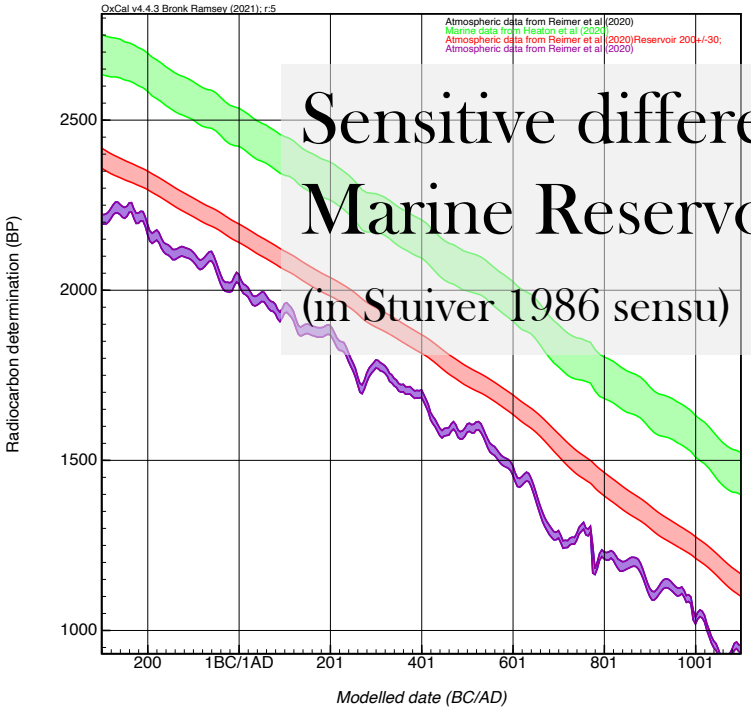




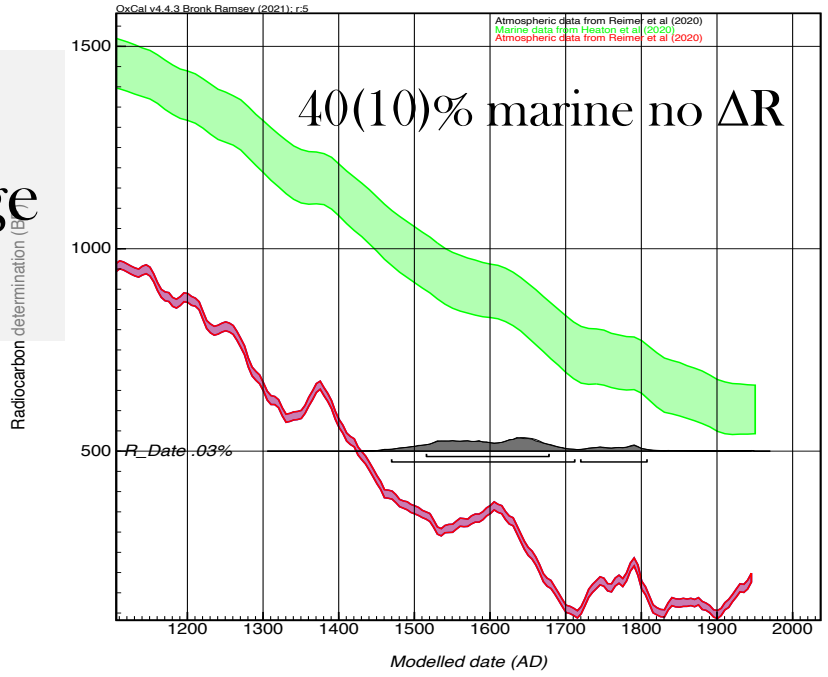


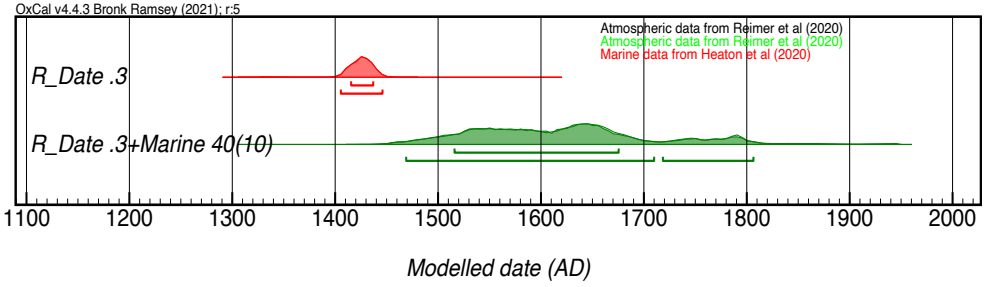


A Genetic History of Precontact Caribbeans

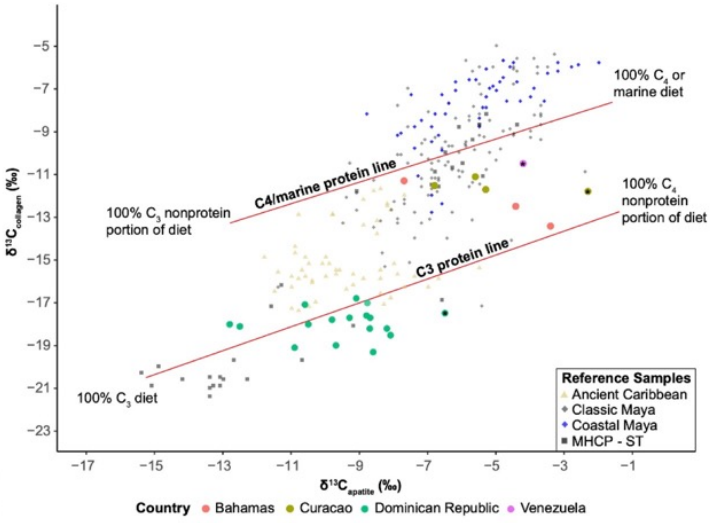


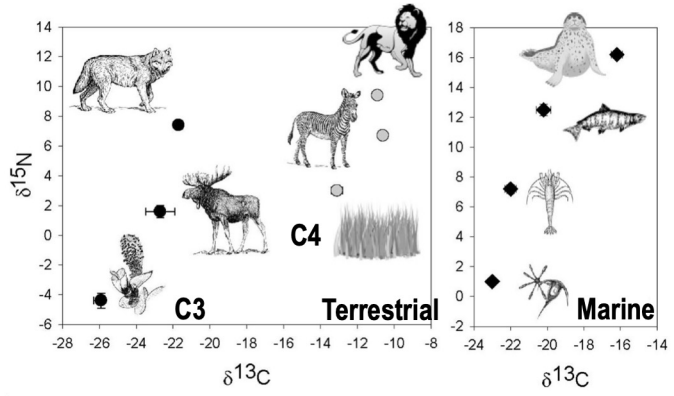
Sensitive difference!
Marine Reservoir Age
(in Stuiver 1986 sensu)

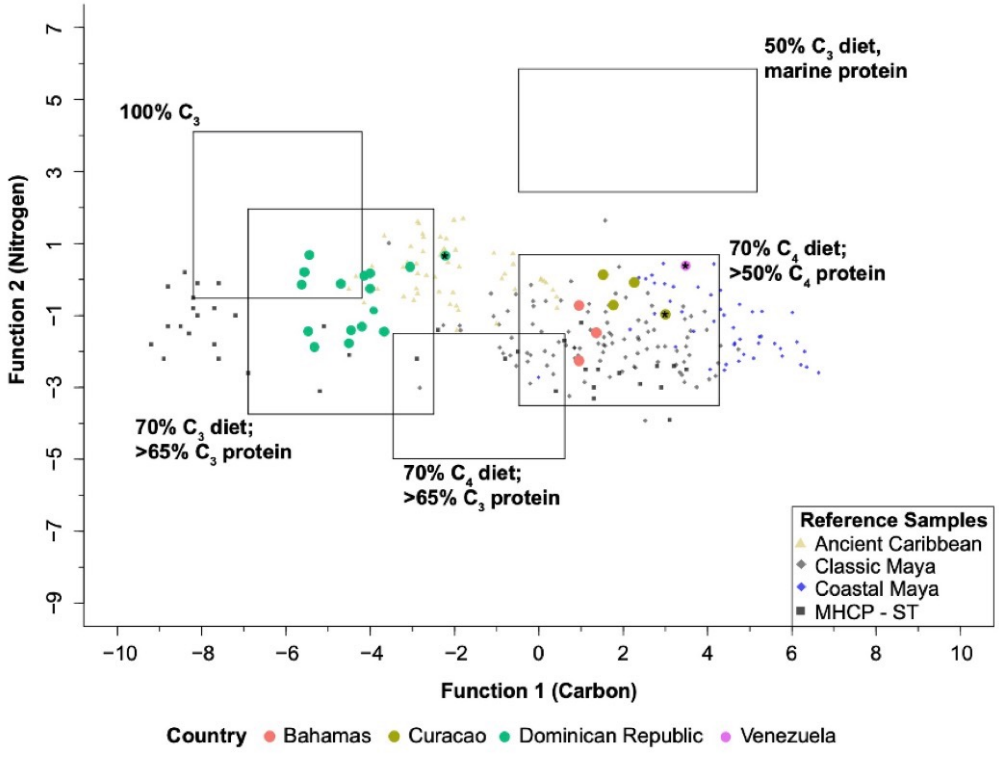




A Genetic History of Precontact Caribbeans







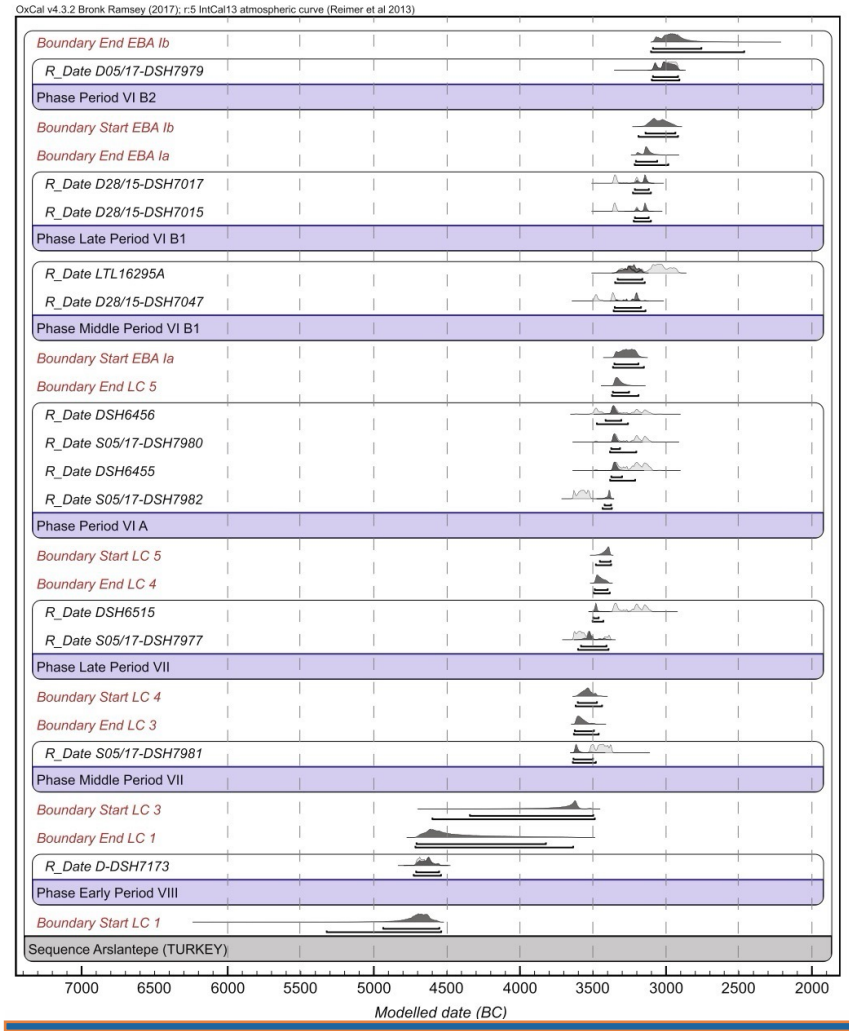
Arslantepe

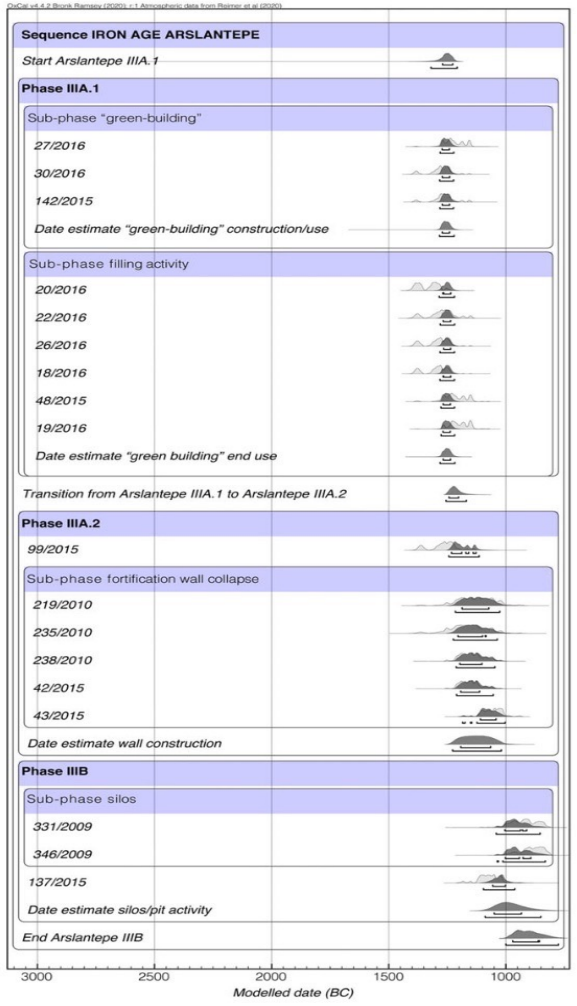
ARSLANTEPE

unesco World Heritage Convention

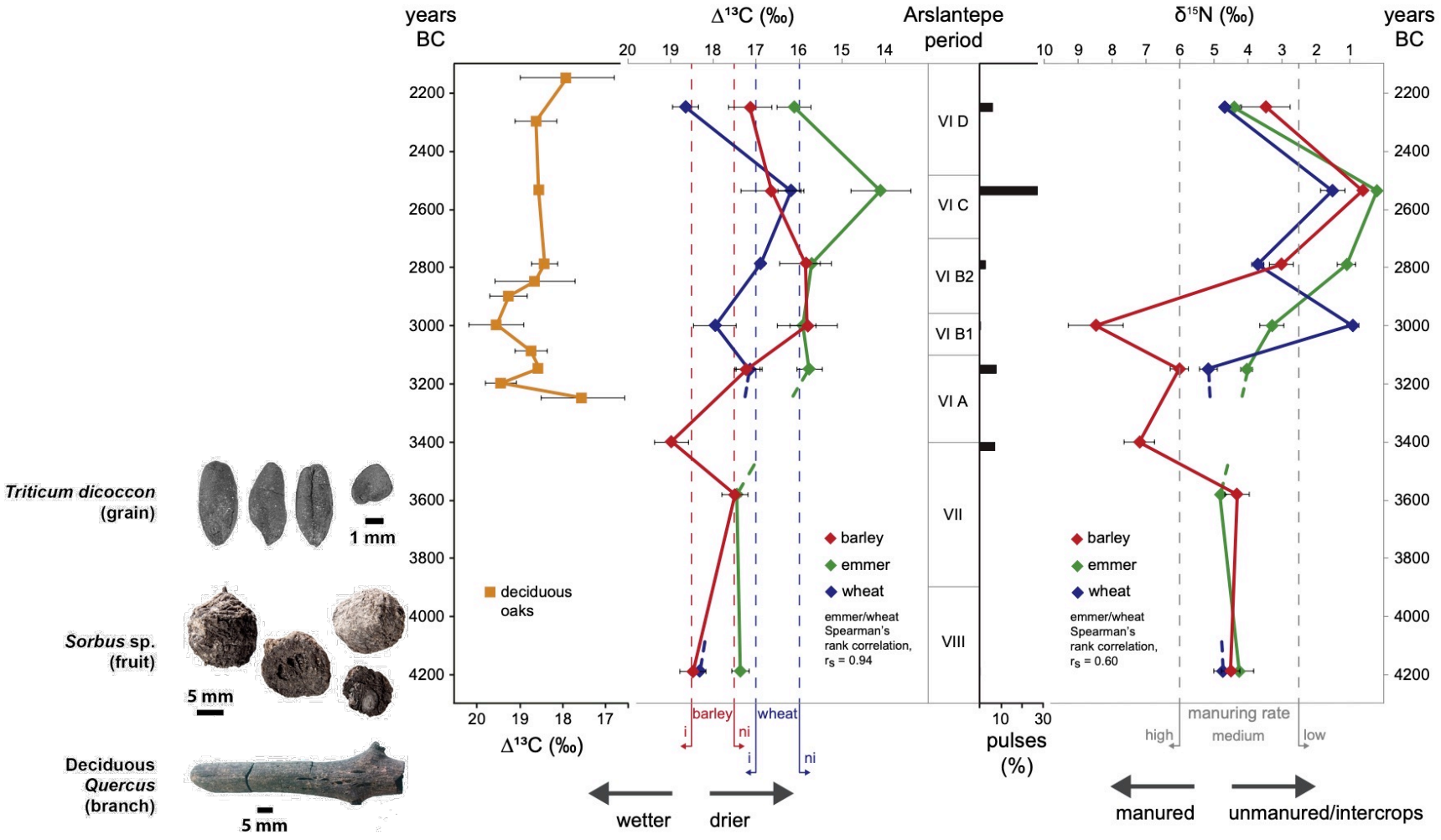
Chronological sequence of Eastern Anatolia	Arslantepe periods	Calendar years BC
Late Roman and Byzantine Age		
Iron Age	II - III	1100 - 712
Late Bronze Age II	IV	1600 - 1200
Late Bronze Age I	V B	1750 - 1600
Middle Bronze Age	V A	2000 - 1750
Early Bronze Age III	**VI D**	**2500 - 2000**
Early Bronze Age II	**VI C**	**2750 - 2500**
Early Bronze Age Ib	**VI B2**	**3000 - 2750**
Early Bronze Age Ia	**VI B1**	**3100 - 3000**
Late Chalcolithic 5 / Late Uruk	**VI A**	**3400 - 3100**
Late Chalcolithic 3-4	**VII**	**3900 - 3400**
Late Chalcolithic 1-2	**VIII**	**4700 - 3900**

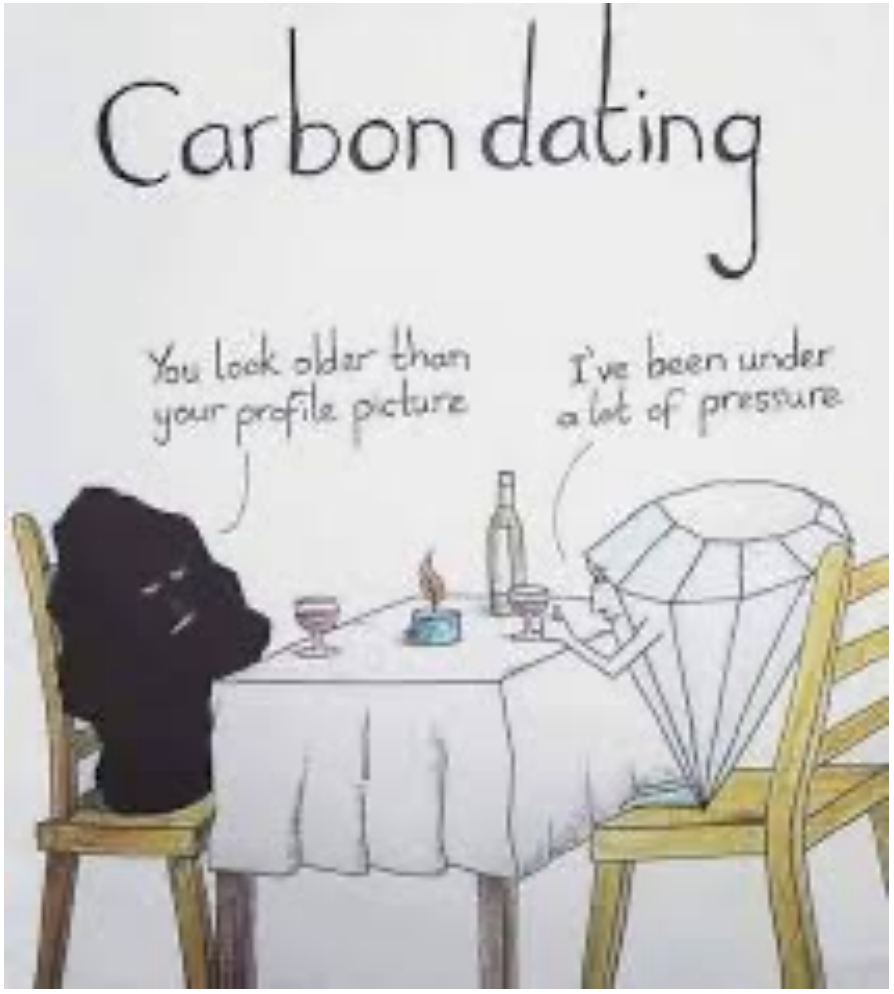
Arslantepe


OxCal v4.3.2 Bronk Ramsey (2017); r:5 IntCal13 atmospheric curve (Reimer et al 2013)
Boundary End EBA Ib
R_Date D05/17-DSH7979
Phase Period VI B2
Boundary Start EBA Ib
Boundary End EBA Ia
R_Date D28/15-DSH7017
R_Date D28/15-DSH7015
Phase Late Period VI B1
R_Date LTL16295A
R_Date D28/15-DSH7047
Phase Middle Period VI B1
Boundary Start EBA Ia
Boundary End LC 5
R_Date DSH6456
R_Date S05/17-DSH7980
R_Date DSH6455
R_Date S05/17-DSH7982
Phase Period VI A
Boundary Start LC 5
Boundary End LC 4
R_Date DSH6515
R_Date S05/17-DSH7977
Phase Late Period VII
Boundary Start LC 4
Boundary End LC 3
R_Date S05/17-DSH7981
Phase Middle Period VII
Boundary Start LC 3
Boundary End LC 1
R_Date D-DSH7173
Phase Early Period VIII
Boundary Start LC 1
Sequence Arslantepe (TURKEY)
7000 6500 6000 5500 5000 4500 4000 3500 3000 2500 2000
Modelled date (BC)


Sequence IRON AGE ARSLANTEPE
Start Arslantepe IIIA.1
Phase IIIA.1
Sub-phase "green-building"
27/2016
30/2016
142/2015
Date estimate "green-building" construction/use
Sub-phase filling activity
20/2016
22/2016
26/2016
18/2016
48/2015
19/2016
Date estimate "green building" end use
Transition from Arslantepe IIIA.1 to Arslantepe IIIA.2
Phase IIIA.2
99/2015
Sub-phase fortification wall collapse
219/2010
235/2010
238/2010
42/2015
43/2015
Date estimate wall construction
Phase IIIB
Sub-phase silos
331/2009
346/2009
137/2015
Date estimate silos/pit activity
End Arslantepe IIIB
3000 2500 2000 1500 1000
Modelled date (BC)

Arslantepe


years BC
Δ13C (‰)
Arslantepe period
δ15N (‰)
years BC
Triticum dicoccon (grain)
1 mm
Sorbus sp. (fruit)
5 mm
Deciduous Quercus (branch)
5 mm
deciduous oaks
barley
emmer
wheat
emmer/wheat Spearman's rank correlation, rs = 0.94
VI D
VI C
VI B2
VI B1
VI A
VII
VIII
pulses (%)
barley
emmer
wheat
emmer/wheat Spearman's rank correlation, rs = 0.60
manuring rate
high
medium
low
wetter
drier
manured
unmanured/intercrops


Carbon dating
You look older than your profile picture
I've been under a lot of pressure

Thanks for your attention!