Australian Government

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Megavolt Accelerator Systems for Environmental Monitoring.

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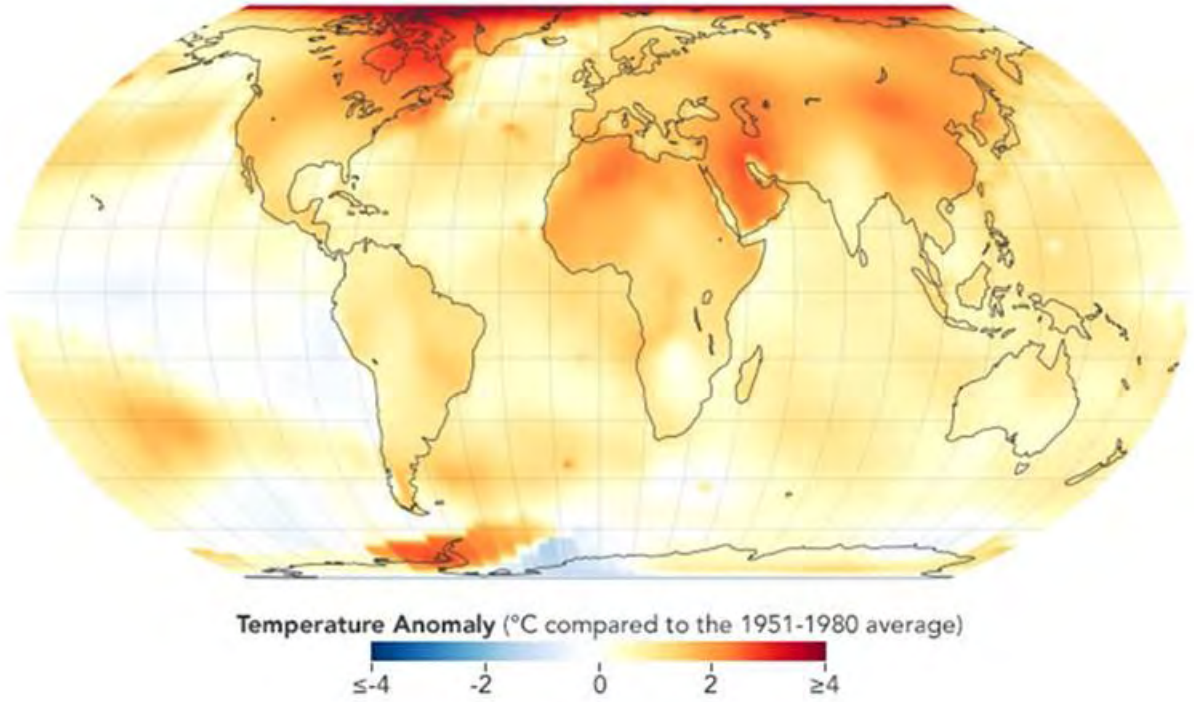
http://www.ansto.gov.au/iba

Science. Ingenuity. Sustainability.

Global Climate Change is Here!



- 2021 was the 6th warmest year since 1880.
- Eight of the top 10 warmest years on our planet occurred in the last decade.
- Global temperatures 0.85°C above the 1951-1980 average.
- 1.1°C increase since Industrial Revolution (late 19th century).
- Green house gases account for ~ +2.5W/m^2 of warming.
- Fine particles (PM2.5) from combustion of fossil fuels scatter radiation back out into space, negative forcing ~ -1.1W/m^2 of cooling.

Without fine particles the global temperature rise would be even higher!!

Source: https://earthobservatory.nasa.gov/images/149321/2021-continued-earths-warming-trend?src=eoa-iotd

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Fine Particle PM2.5 Air Pollution Studies:

- Air pollution is driven by urbanisation.
- Everyday ~100,000 people globally move into cities!
- Since 2008, more than 50% of the world's population lived in cities.
- Cities become megacities with populations > 10 million. Currently more than 37 megacities globally. 8 of top 10 in Asia.
- Generating more fine particle pollution, shortens life expectancy. The average life expectancy in an Asian megacity is reduced by 5-6 years by pollution.
- Even annual average PM2.5 levels of 10μg/m^3 have health impacts. Some megacities PM2.5 >50μg/m^3
- Accelerator –based Ion Beam Analysis (IBA) PIXE, PIGE, RBS can characterize and identify sources of fine particle PM2.5 pollution.
- Couple IBA data with recent powerful statistical source fingerprinting and apportionment techniques.
- Combine source fingerprinting with meteorological data to trace long range transport (LRT) of PM2.5.

Manila on a 'clear day'

Manila on a smoggy day

Source: Zhu et al WMO/ IGAC Impacts of Megacities on Air Pollution and Climate, GAW Report No. 205, September 2012.

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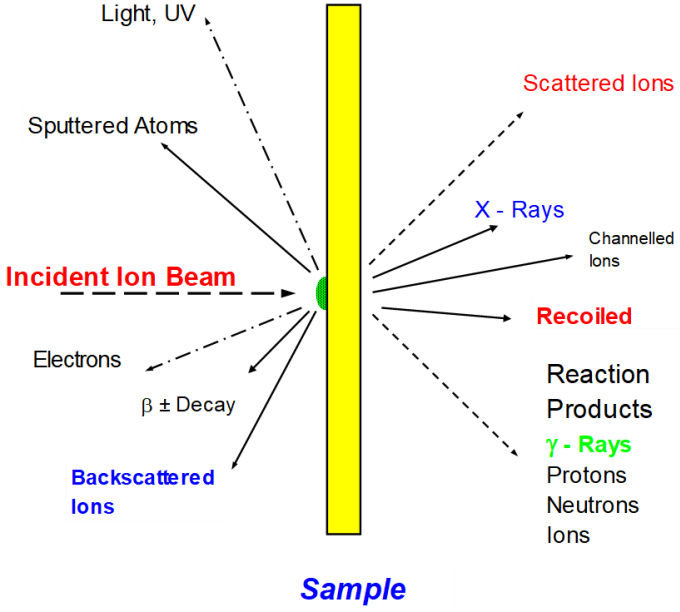
Fine Particle PM2.5 IBA Characterisation

Typical fine mass filters for 24 hour collection weighs ~300µg.

Filters analysed using nA beams of MeV protons and IBA techniques give over 30 different elemental and chemical species.

Analysis does not destroy the sample.

Exposed stretched Teflon filter, optimised for IBA analysis.



ANSTO 2MV STAR accelerator

PIXE – Interactions with electrons, characteristic keV x-rays from Al to U
PIGE – Interactions with nucleus, gamma rays for light elements (Mg, Al, F, Na..)
RBS – Rutherford Backscattering for C, N, O ..
PESA – Particle Elastic Scattering analysis for total H content.

These 4 techniques can be run simultaneously in a few minutes and provide data from H to U with sensitivities of (µg/g) on sample sizes as small as pg.

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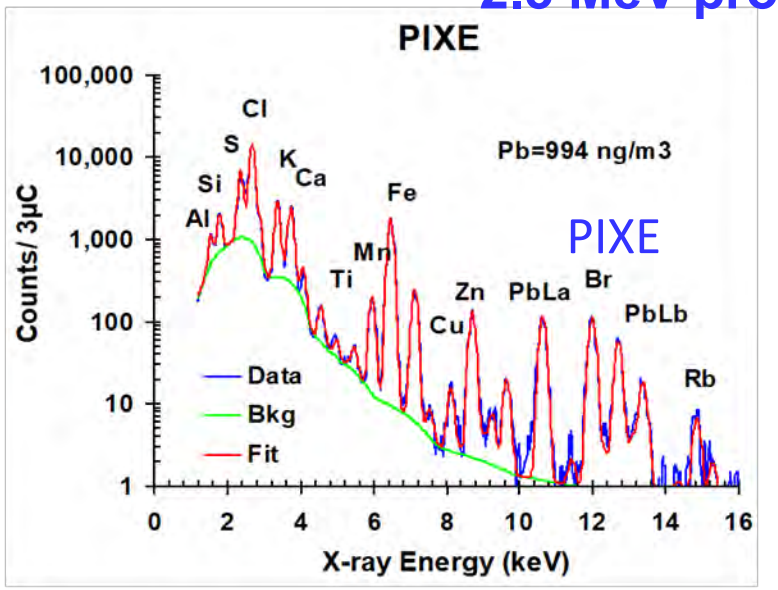
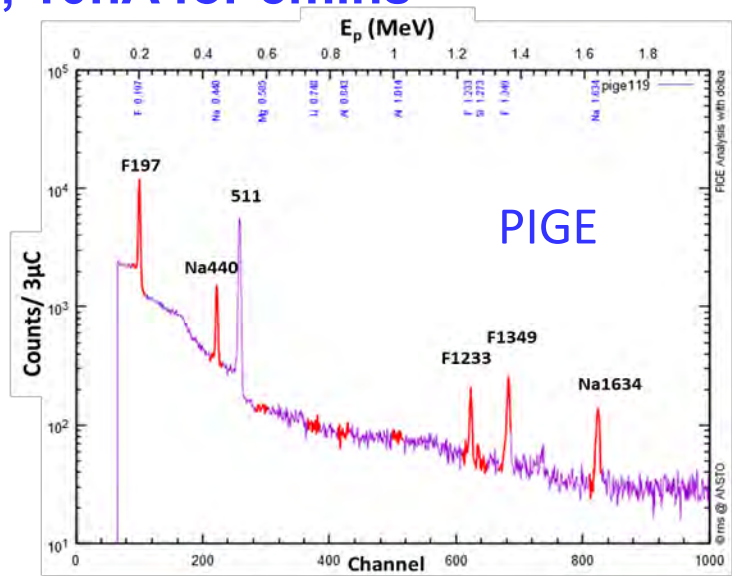
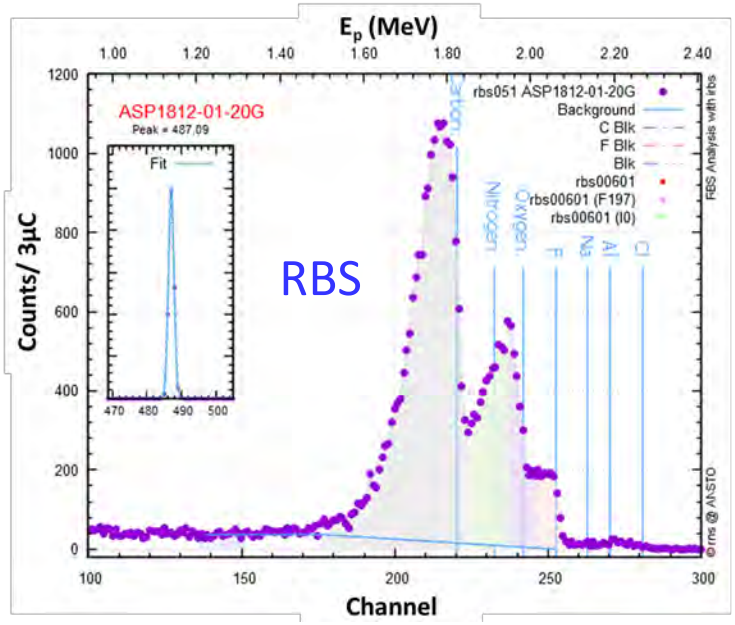
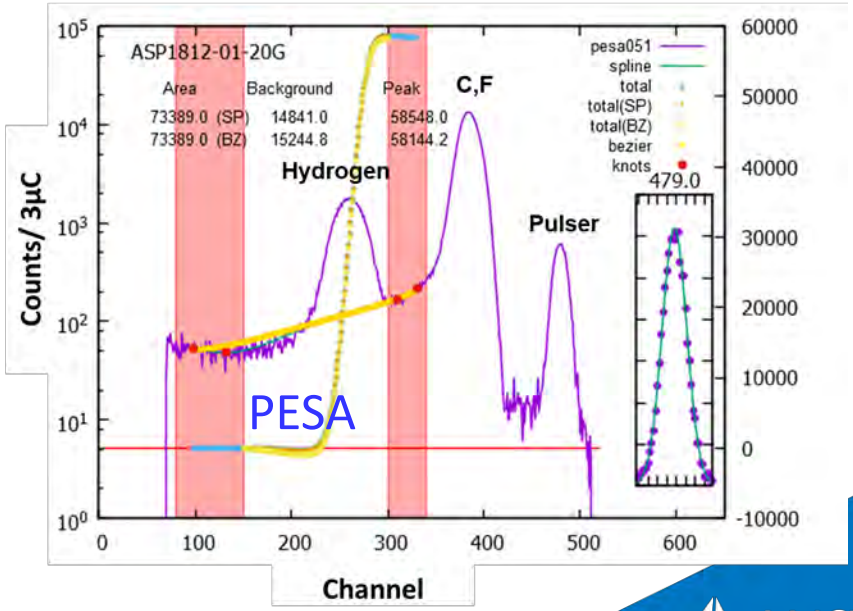
IBA Spectra – iBAT Analysis Code

2.5 MeV protons, 10nA for 5mins









Measure >30 elements from H to U, run 100 samples a day, non-destructively

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Modern trends combine:

- IBA composition
- Source fingerprinting and apportionment
- Back trajectory wind speed and direction.

Positive Matrix Factorisation (PMF)

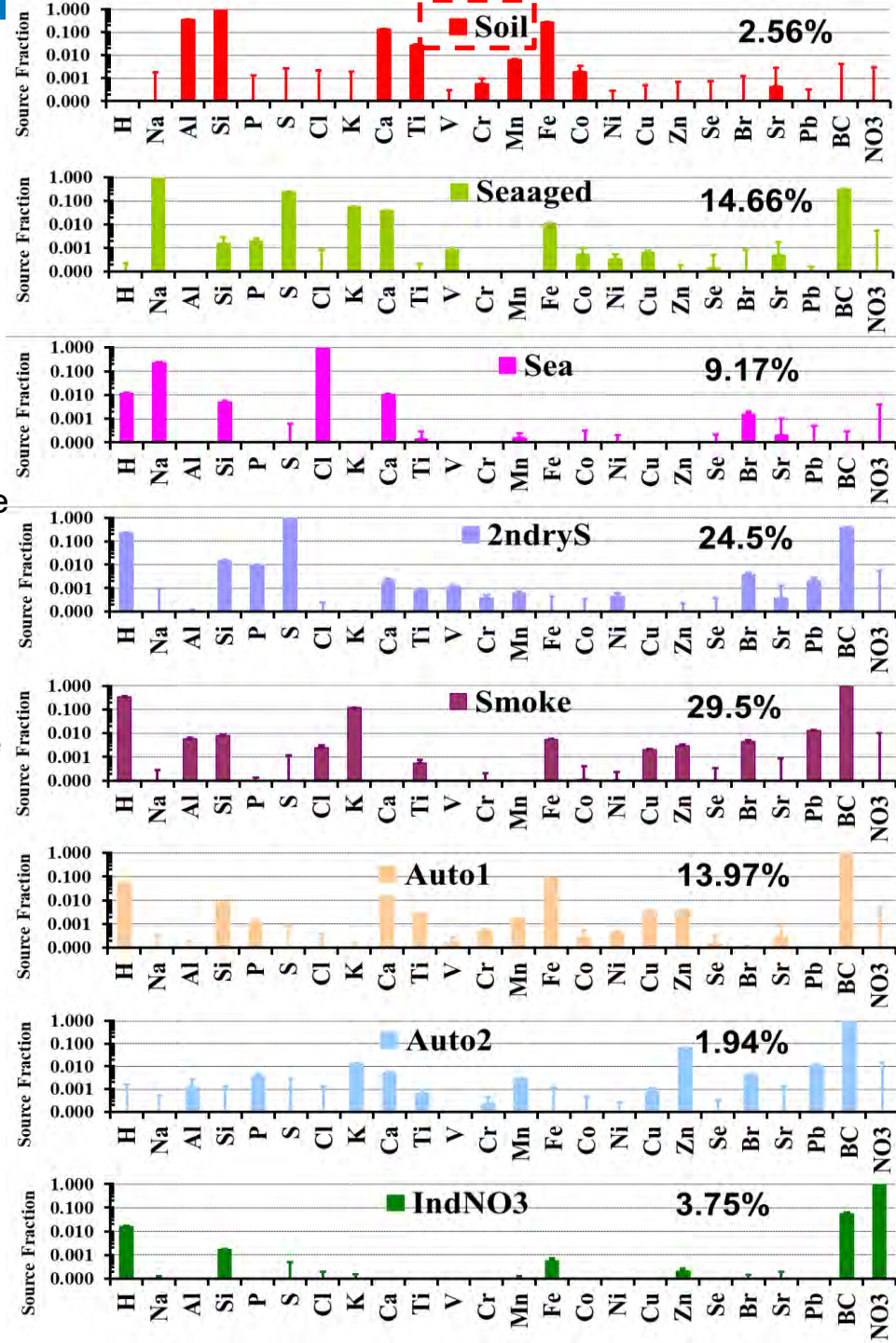
$$M_{i,j} = \sum_{k=1}^{p} F_{k,j} * G_{i,k} + E_{i,j}$$

M_{ij} is a daily mass matrix, F_{kj} are p fingerprints using the j measured elements and G_{ik} is the daily contributions matrix for each of the p fingerprints. E_{ij} is error term to be minimized.

Opposite is the *p=8* fingerprint fit to 2,302 sampling days between January 1998 and February 2022. These 8 fingerprints divide the daily PM2.5 mass (Av.=8.1±5.2 μg/m^3) into 8 separate and distinct sources.

The *Soil* fingerprint was driven by Al, Si, Ca, Ti and Fe. The (Al/Si) ratio was typical of aluminosilicates.
The *Sea* fingerprint was driven by Na and Cl in the correct ratio and traces of Si, Ca and Br.
The *Smoke* fingerprint was driven by H reflecting the organic component, K indicative of biomass burning and BC for the soot content. Other traces such as Cl, Zn, and Br were typical of biomass burning.

http://www.helsinki.fi/~paatero/PMF/pmf2.zip



HYSPLIT Hourly Back Trajectories for Soil at Liverpool for 2001-22

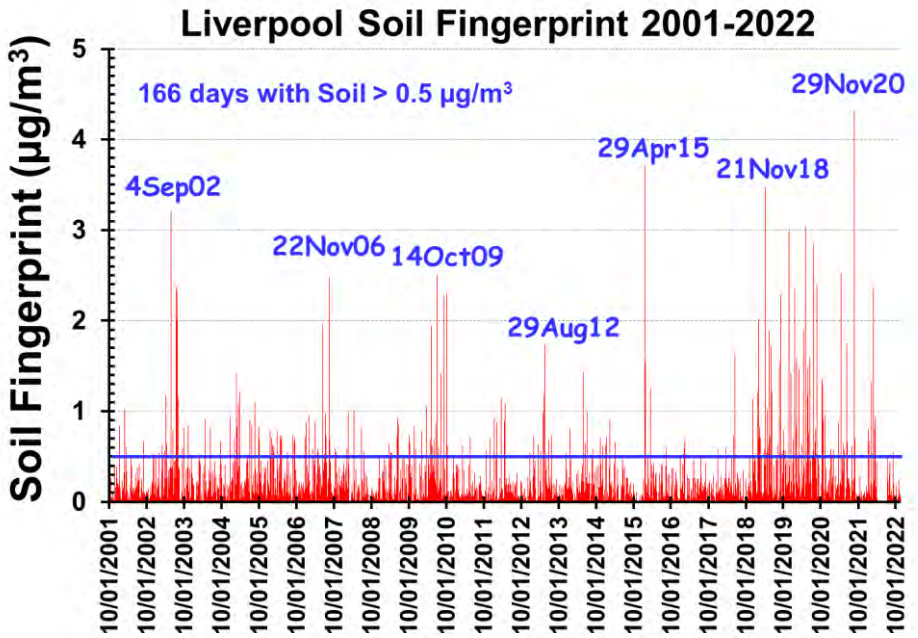
Desert dust storm in Birdsville, QLD, Australia.
27 January 2006.

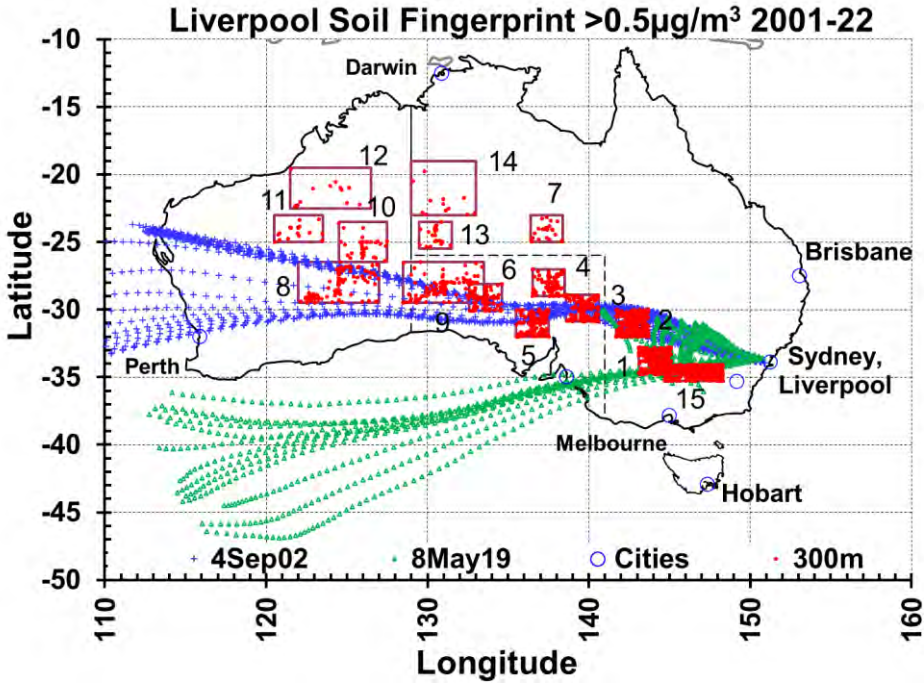
300m Desert	%Soil	Desert	%Soil
15Riverina	41.2	6LakeEyreNorth	2.1
1LakeMungo	25.6	10Gibson	0.7
2LakeWindaunka	11.8	7SimpsonDesert	0.5
4OlympicDam	5.2	13GrtSandyE	0.5
3EastFlinders	4.6	11LitSandy	0.4
9GreatVicE	2.4	12GrtSandyW	0.3
8GreatVicW	2.2	14Tanami	0.3
5EmuFieldsSalt	2.2		

In past 22 years 41% of the dust measured in the Sydney basin (>0.5µg/m^3) at Liverpool had trajectories through the agricultural region, Riverina Box15.

The desert regions (boxes 1-14) tended to contribute only on occasional extreme Soil days.

HYSPLIT: http://ready.arl.noaa.gov/HYSPLIT.php





Accelerator Mass Spectrometry (AMS) - Isotopic Dating

Measurements out to 10 half-lives

^{14}C

5,730yrs

$1;10^{-12}$

100yrs — **60,000**yrs

$^{14}_{7}N + n \rightarrow {}^{14}_{6}C + p$

stratosphere by thermal neutrons

Climate and archaeology

^{36}Cl

301,300yrs

$1;7\ 10^{-13}$

30,000yrs — **3,000,000**yrs

Neutrons on ^{35}Cl, proton spallation of ^{39}K and ^{40}Ca.

Ground water management and geological exploration

^{10}Be

1,390,000yrs

Trace

Cosmic ray interactions with ^{14}N, ^{16}O. Spallation of ^{16}O, ^{27}Al, ^{28}Si and ^{56}Fe.

500,000yrs — **14,000,000**yrs

Soil erosion and geomorphology

- Megavolt accelerator systems can accelerate most isotopes in the periodic table. Individual atom counting.
- Can measure isotopic ratios to $1:10^{15}$ with a precision of 0.5%.
- Match the isotope half-life to the timescale required.

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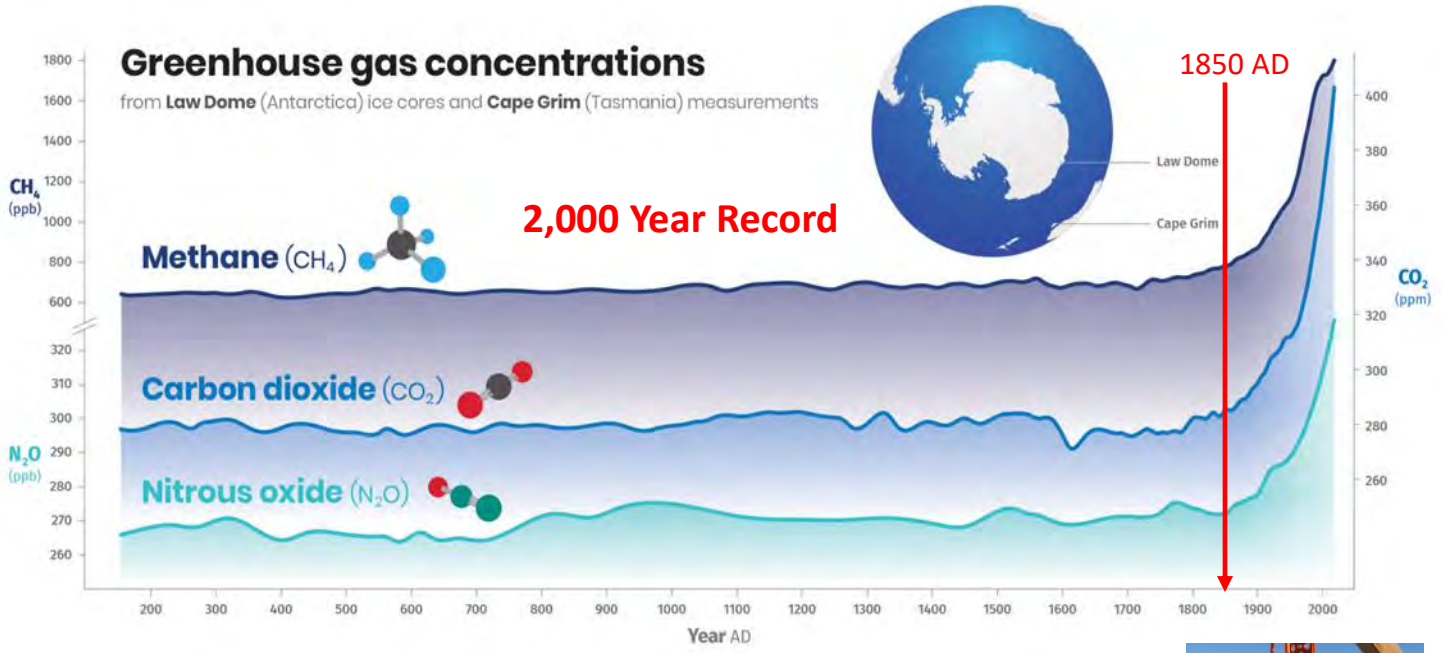
Trapped CO_2 in Antarctic Ice Cores

The three principal greenhouse gases methane, carbon dioxide and nitrous oxide increased dramatically over the industrial period.



In last 2,000 years;

CH_4 – increase ~ 700 ppb to ~1,800 ppb (x25 stronger GHG than CO_2).

CO_2 – increase ~ 280 ppm to ~ 410 ppm.

N_2O – increase ~ 270 ppb to ~ 330 ppb.

Major increases occurred since 1850 AD.

Current levels unprecedented in the last 800,000 years.

- Falling snow which compacts with time traps and preserves gases.
- Air samples as old as 800,000 years have been recovered from Antarctica.
- 1Tonne of ice core contains ~20µg of carbon – ^{14}C AMS works with µg samples.
- ^{14}C-AMS good at distinguishing between modern carbon (livestock, landfill) and ancient carbon (fossil fuels, permafrost).

Accelerator based ^{14}C Measurements

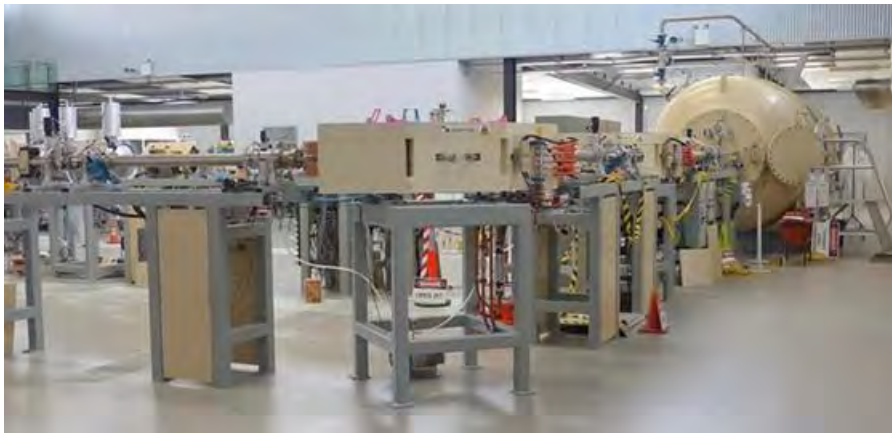
Extraction of solid C from gaseous CO_2 requires microgram sample preparation capabilities, with no cross- contamination.
Microgram carbon samples are pressed into cathodes for insertion into the accelerator ion source.

Megavolt machines accelerate the isotopes through torturous paths from the ion source to the detector.
Only a given isotope with the required (ME/q^2) reaches the detector.
Isotopic selectivity can be as good as $1:10^{15}$.
Measure 10 half-lives, precision ±0.5%.

A micro-furnace system

Cathode and ion source cathode wheel

High energy beamlines for a 6MV Tandem Accelerator



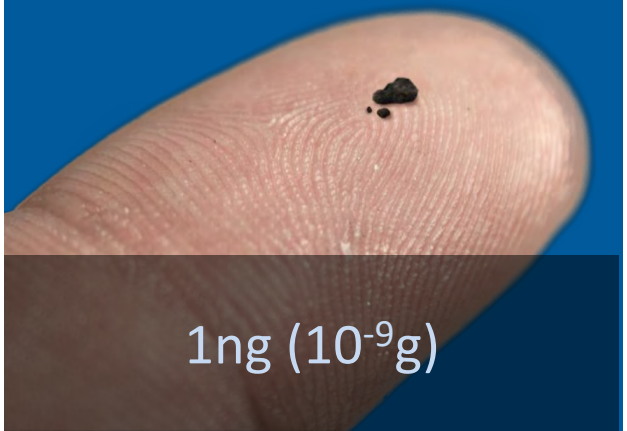
Layout for a 6MV IBA and AMS Tandem Accelerator

Why use accelerators?

Very sensitive

1 in 10^{23} atoms

Very small samples



1ng (10^{-9}g)

Very short processing time

Minutes to hours
not days to weeks

Acknowledgements

I would like to acknowledge the valuable help provided by the accelerator staff at ANSTO with sample preparation, dispatch and analysis, Local Councils and industry groups for changing daily ASP filters at their sites and the Australian National Collaborative Research Infrastructure Scheme (NCRIS) for funding the Centre for Accelerator Science.

Thank you for your attention

Questions?

Info: http://www.ansto.gov.au/ASP

http://www.ansto.gov.au/IBA

http://www.ansto.gov.au/ASPdatabases

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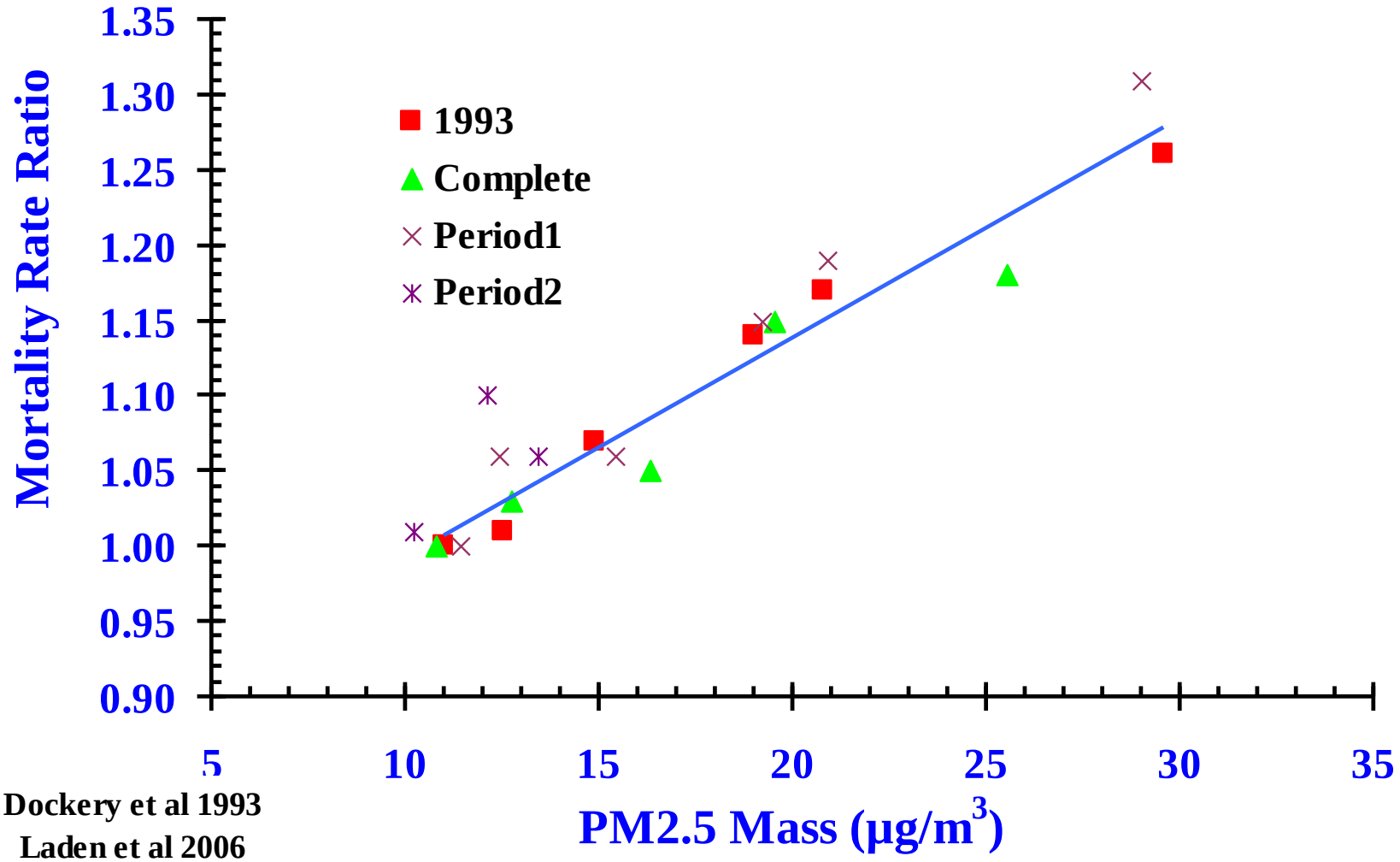
Summary

- The 4 simultaneously obtained IBA spectra of PIXE, PIGE, RBS and PESA are ideal to analyse most key elements (H to Pb) of concern for fine particle (PM2.5) air pollution studies. IBA is a non-destructive technique.
- Typical IBA sensitives are around 1-10 ng/m^3 of air sampled after 3μC runs (10nA for 6 mins) which is more than adequate when total mass concentrations are ~ 10 μg/m^3.
- PMF source apportionment splits the PM2.5 mass into 7-9 different source fingerprints including, windblown soil, secondary sulfates, sea spray, automobiles, smoke from biomass burning and industrial emissions.
- PMF fingerprints couples with back trajectory wind speeds and directions identify the source fingerprint locations and help to better understand long range transport of air pollution.
- AMS techniques using selected isotopes such as ^{14}C, ^{36}Cl and ^{10}Be provide a very broad range of dating methods applicable to environmental and climate change studies.
- AMS can detect isotopic ratios to $1/10^{15}$ with precisions down to 0.5% on samples as small as 10 μg.

Relative Mortality Rate Ratios
6 US Cities



Dockery et al 1993
Laden et al 2006

Appears to be no lower threshold for PM2.5 particles
What component of the mass is producing this death rate?

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