The Technology of Laboratory Astrophysics

Ian Lyon

Isotope Geochemistry and Cosmochemistry Group,
School of Earth, Atmospheric and Environmental Science,
University of Manchester, Manchester M13 9PL

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Scale of the problem

- Dust in the laboratory
- Micrometer to Nanometer in size
- SiC, graphite, Corundum, TiC, Nanodiamonds
- Most grains measured in the laboratory are >1μm. Most circumstellar grains are <1μm

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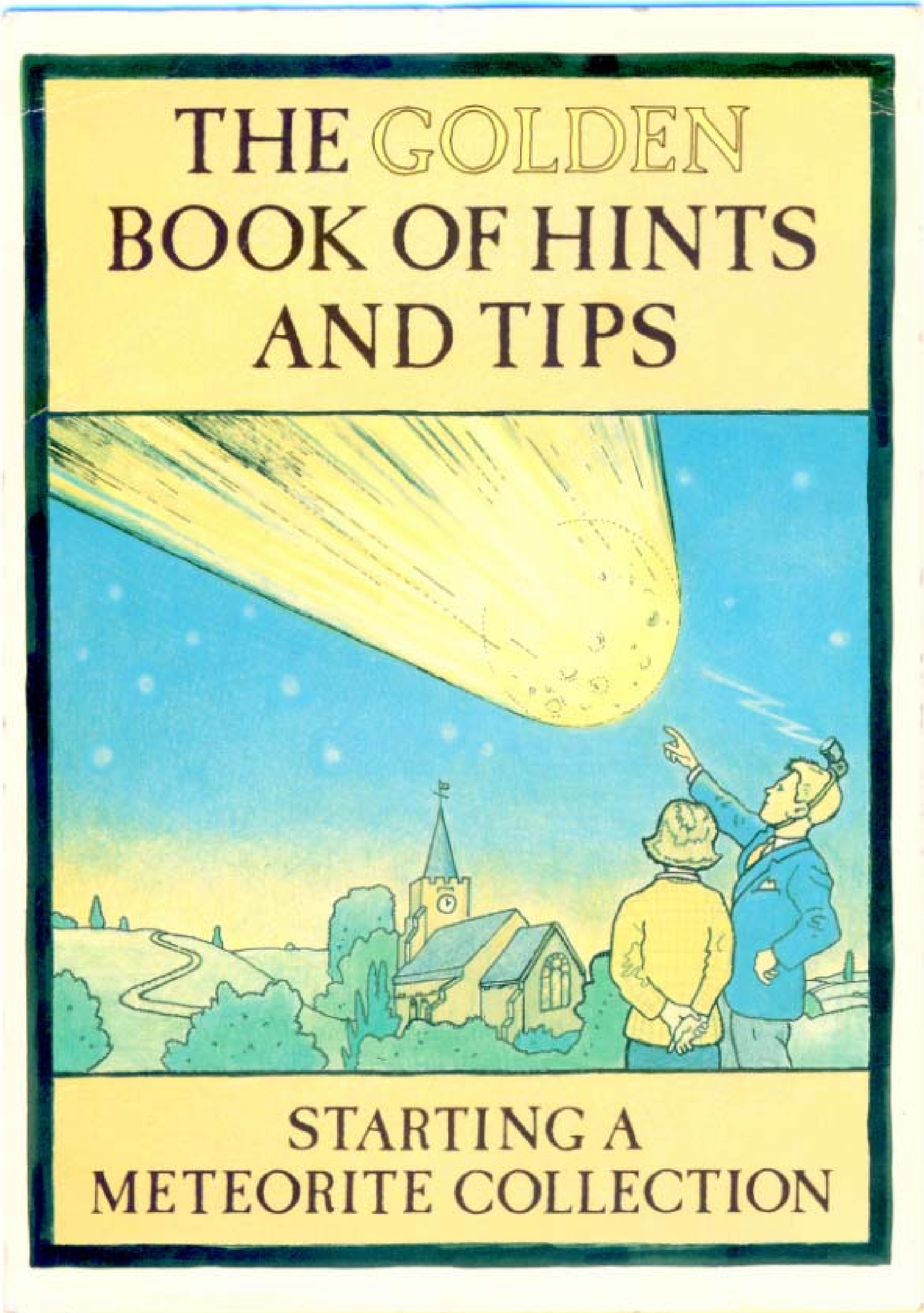
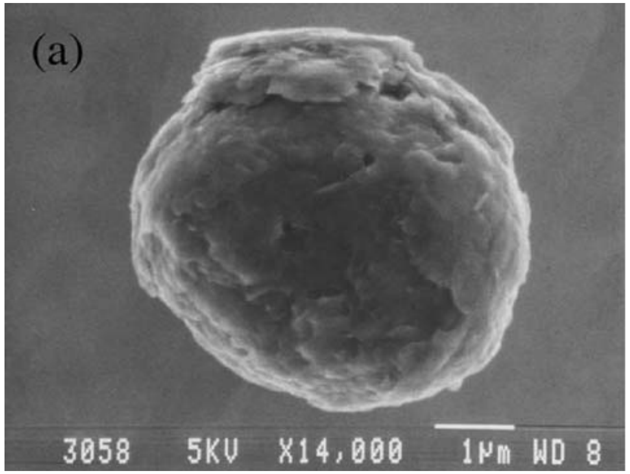
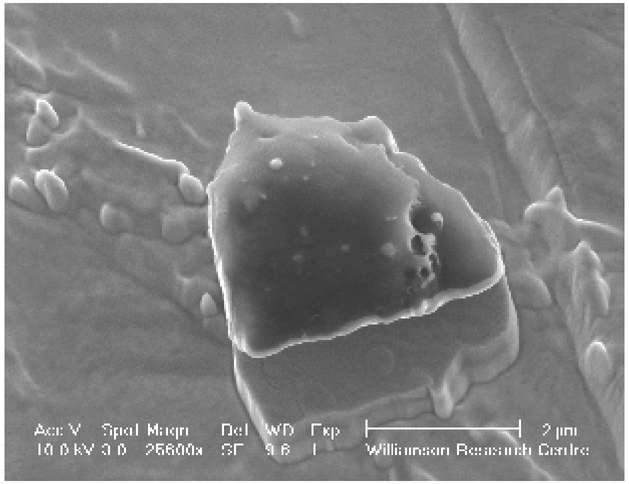

THE GOLDEN
BOOK OF HINTS
AND TIPS
STARTING A
METEORITE COLLECTION

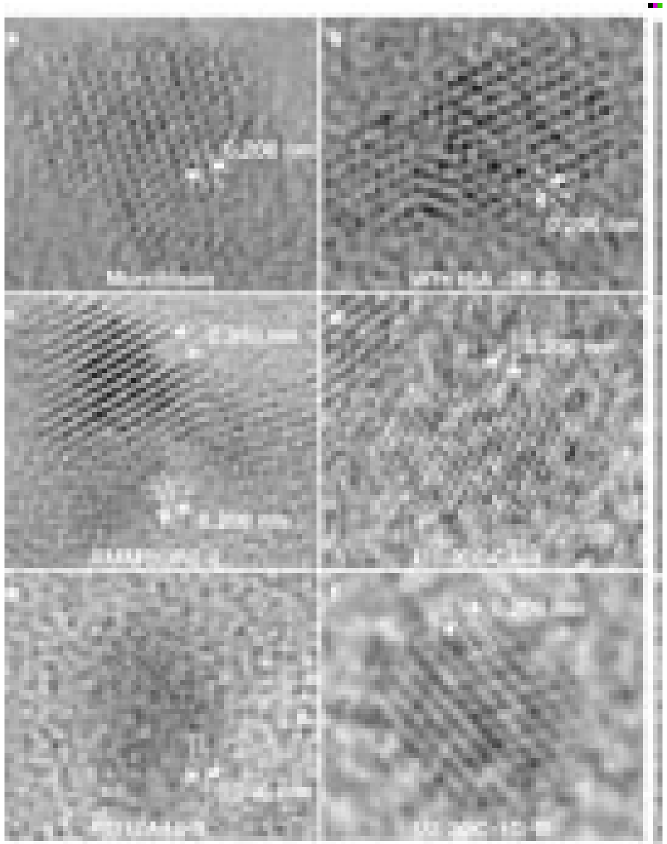
Presolar Grains



(Graphite grain Lodders and Amari (2005) *Chem. der Erde- Geochem.* **65**, 93)



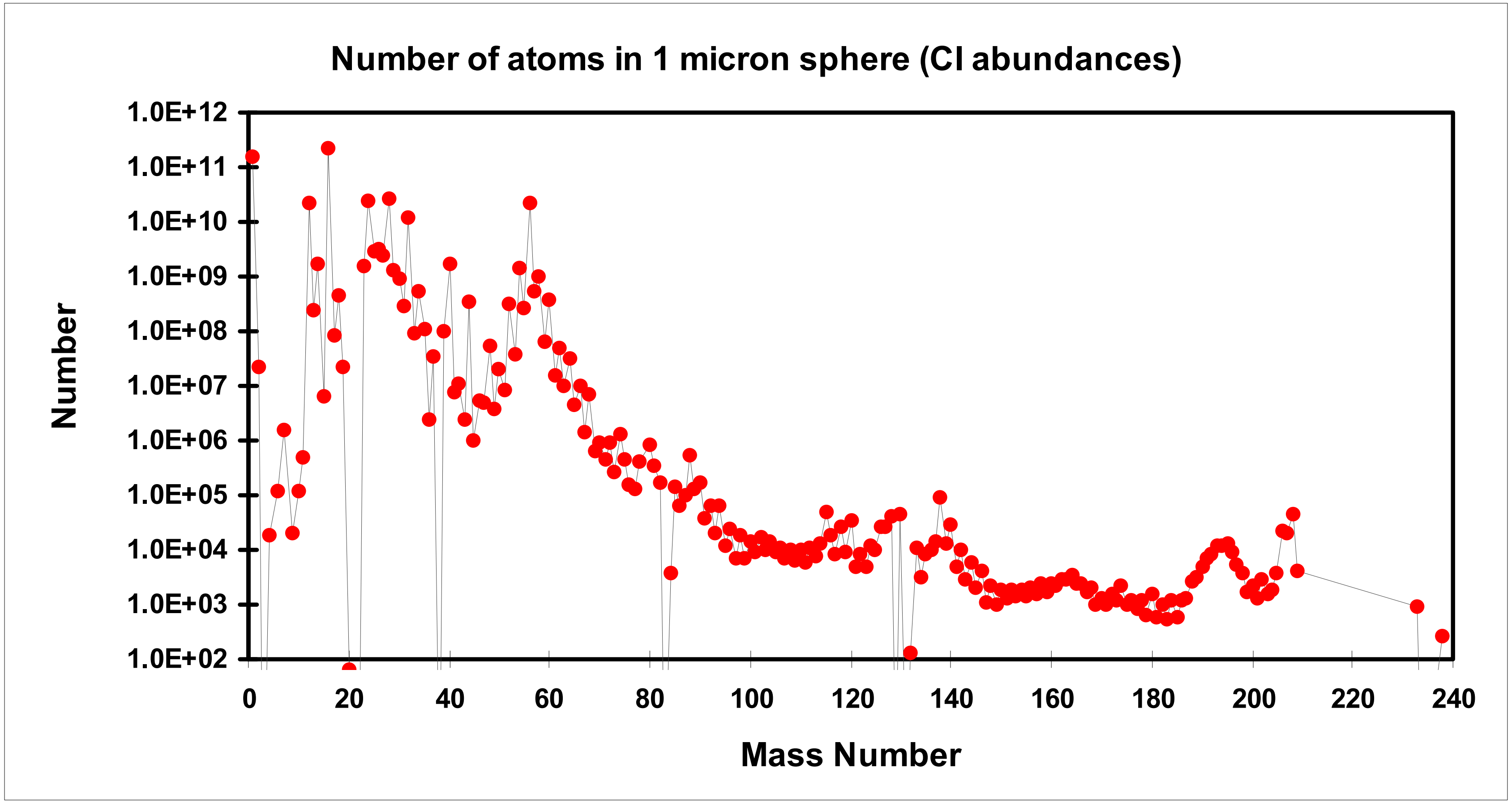
SiC grain (Manchester)



Nanodiamonds

Dai et al, Nature, 2002

Scale of the problem



Analysis

Elemental Analysis

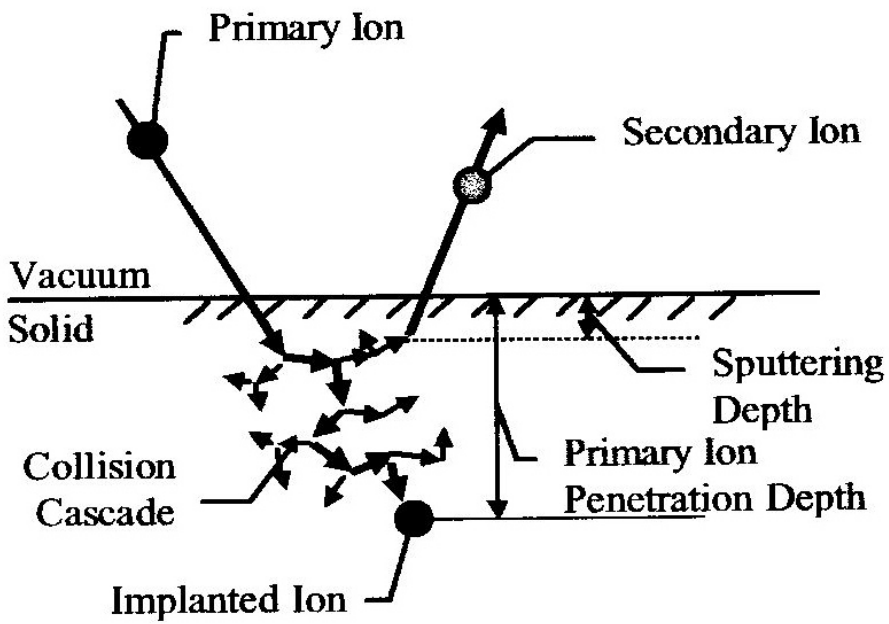
- Electron beam methods
- X-ray methods
- Ion beam methods

- (If you want isotopic information, currently no alternative to extracting atoms from the sample and analysing them in a mass spectrometer – ie ion sputtering, which destroys the sample)

Ion Beam Methods

DC ion beam or pulsed ion beam

Same fundamental physics



Ion Beam Methods

DC ion beam – use magnetic sector mass spectrometer to analyze different masses sputtered from the material

Pulsed ion beam – use time-of-flight to mass disperse the secondary ions

Scale of the problem

- Ionization efficiencies are typically 0.01-1% (varies by element)

- Note that for micrometer-sized grains, if require say ‰ precision on carbon, oxygen, nitrogen isotope ratios – need to remove at least ~10^8-10^9 atoms from the sample

- For elements at the heavy end of the periodic table, have 10^3-10^4 atoms total so may detect 10-100 ions IF we consume the whole of the grain (*and we're lucky and have a following wind*)

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Ion Beam Methods

Exemplar of the DC ion beam method is the NanoSIMS

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Ion Beam Methods

Spatial resolution down to 50nm and high mass resolution allowing precise analysis of isotopic ratios of 1 or 2 elements

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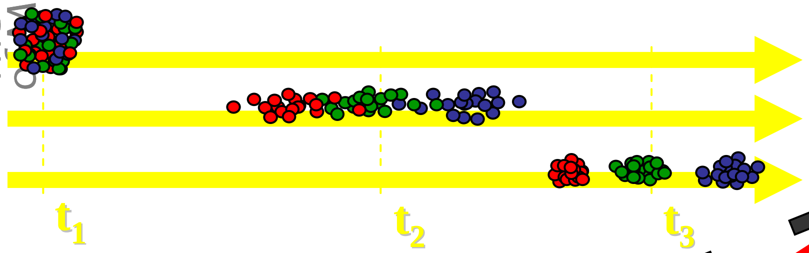
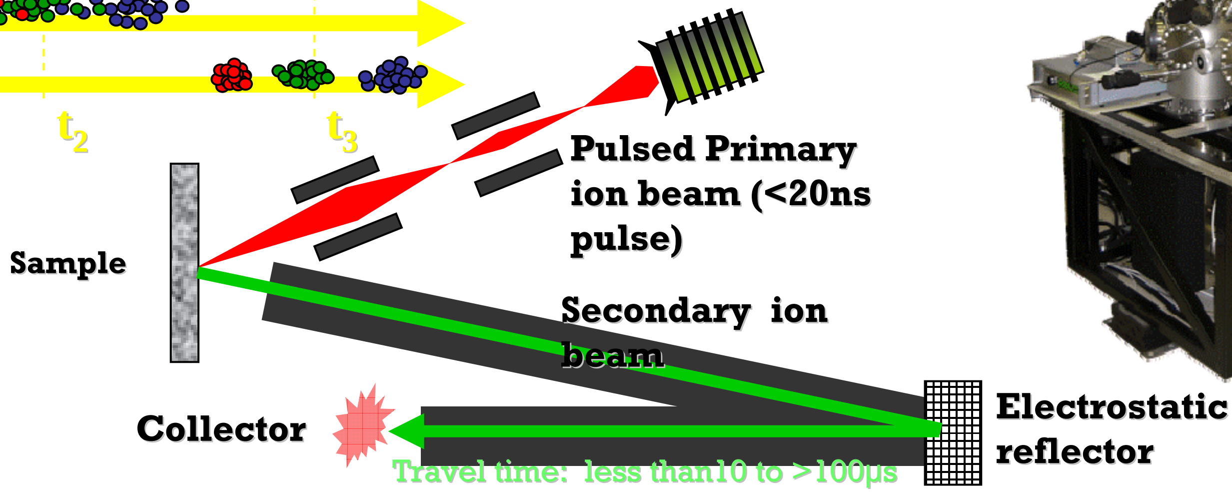
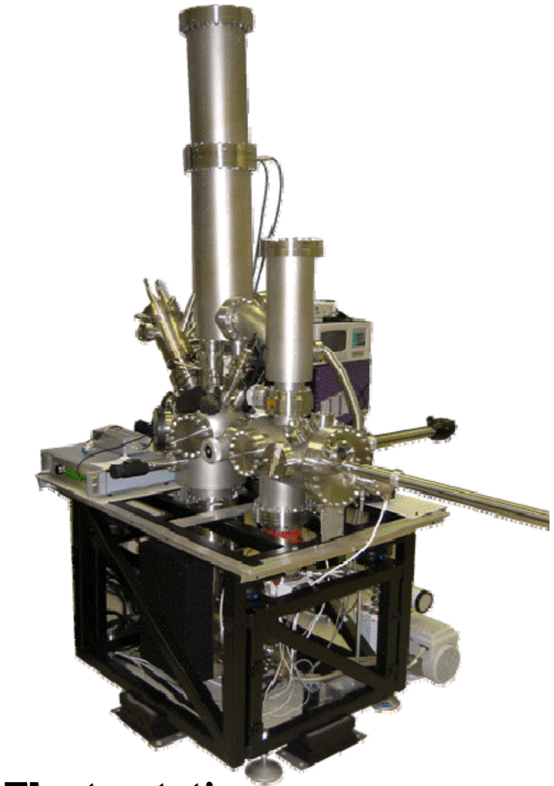
TOFSIMS Analysis

- Sub-micron spatial resolution and high mass resolution.
- Pulsed primary ion beam.
- Secondary ions separated according to their time-of-flight.
- Trace element depth profiles.

TOF-SIMS concept

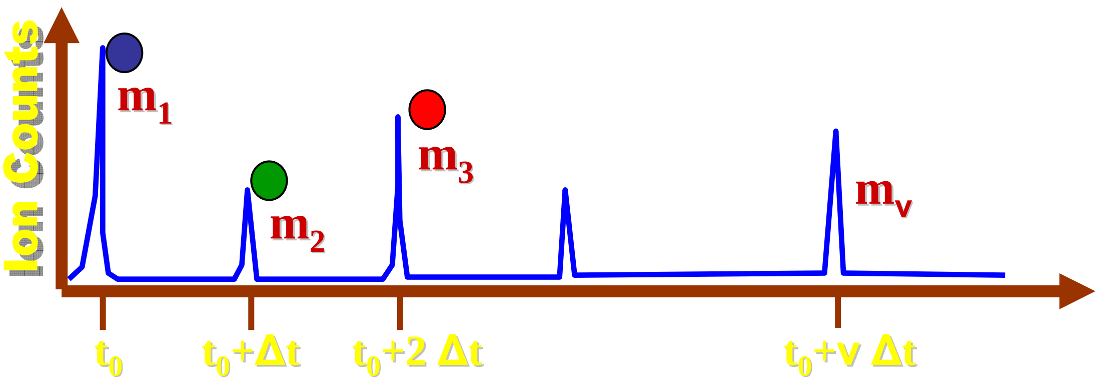


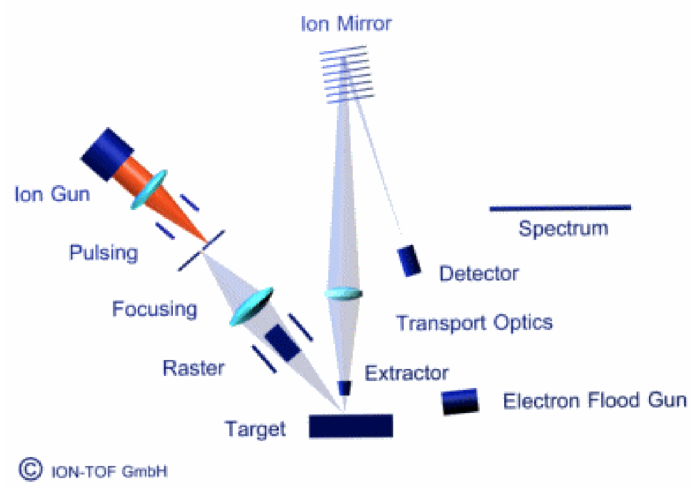




$$t = \frac{D}{\sqrt{2E}}\sqrt{m}$$

$$m_1 < m_2 < m_3 < m_n$$





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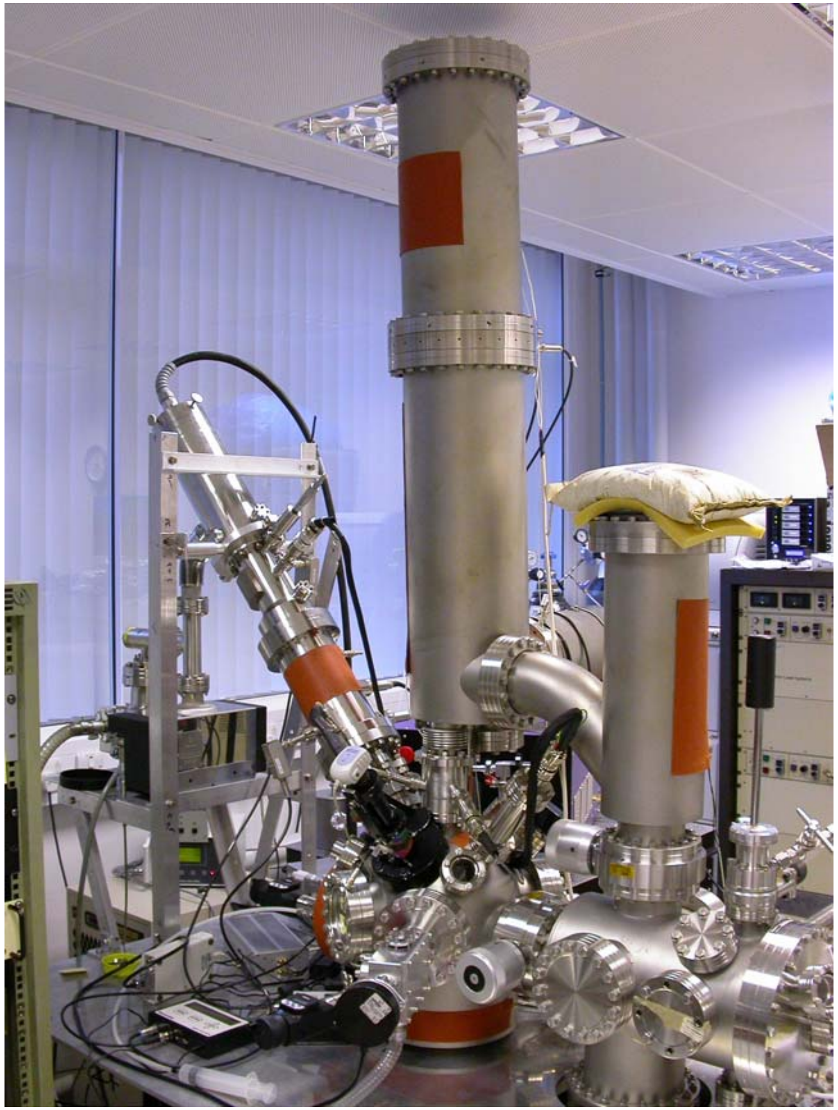
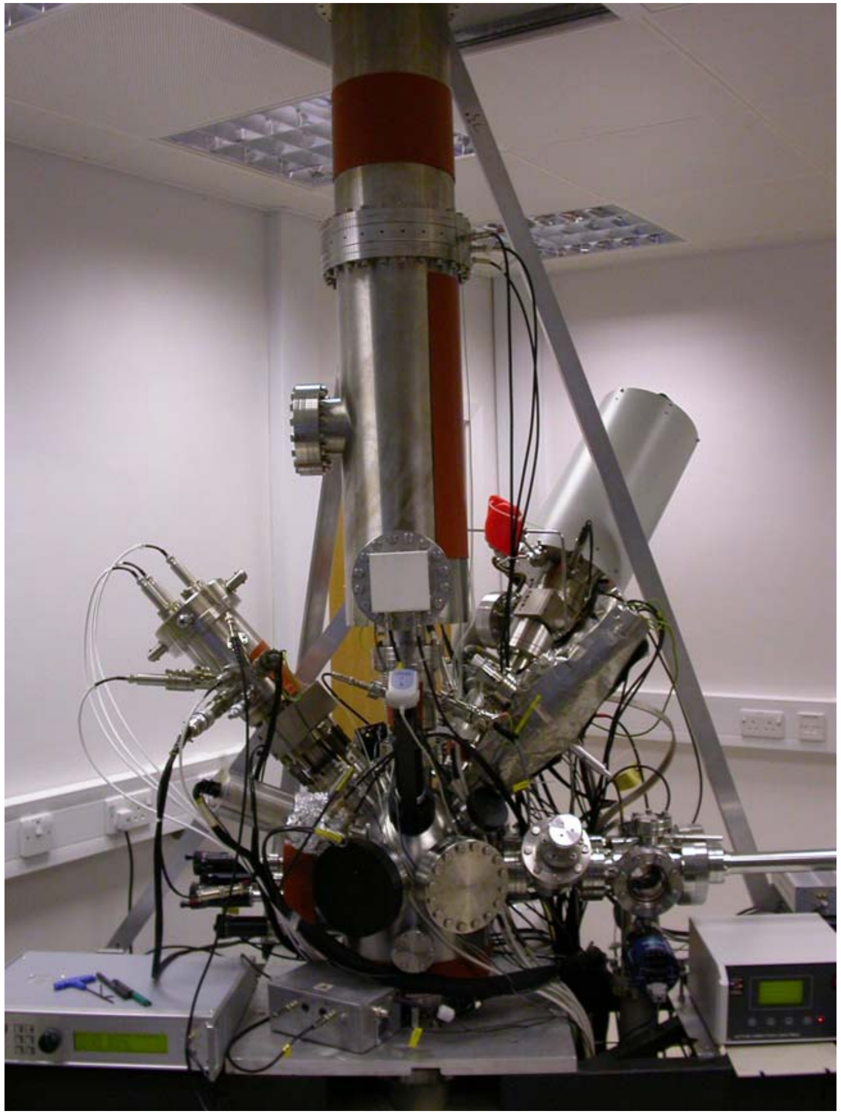
IDLE2 and IDLE3





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TOFSIMS Analysis

Mass resolution is poorer than magnetic sector instruments (but is getting better and is now quite good).

Duty cycle is poor – often 10^{-3} – 10^{-4}
(That means that you eat away the sample much more slowly than dc SIMS instruments – but analyses take correspondingly longer to gain equivalent precision from numbers of secondary ions counted).

Short pulses to get high mass resolution are also more difficult to keep stable at the same point on the sample to acquire high spatial resolution.

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Next Generation Analysis

Combining TOFSIMS capability for analysing everything simultaneously with DC beam capability

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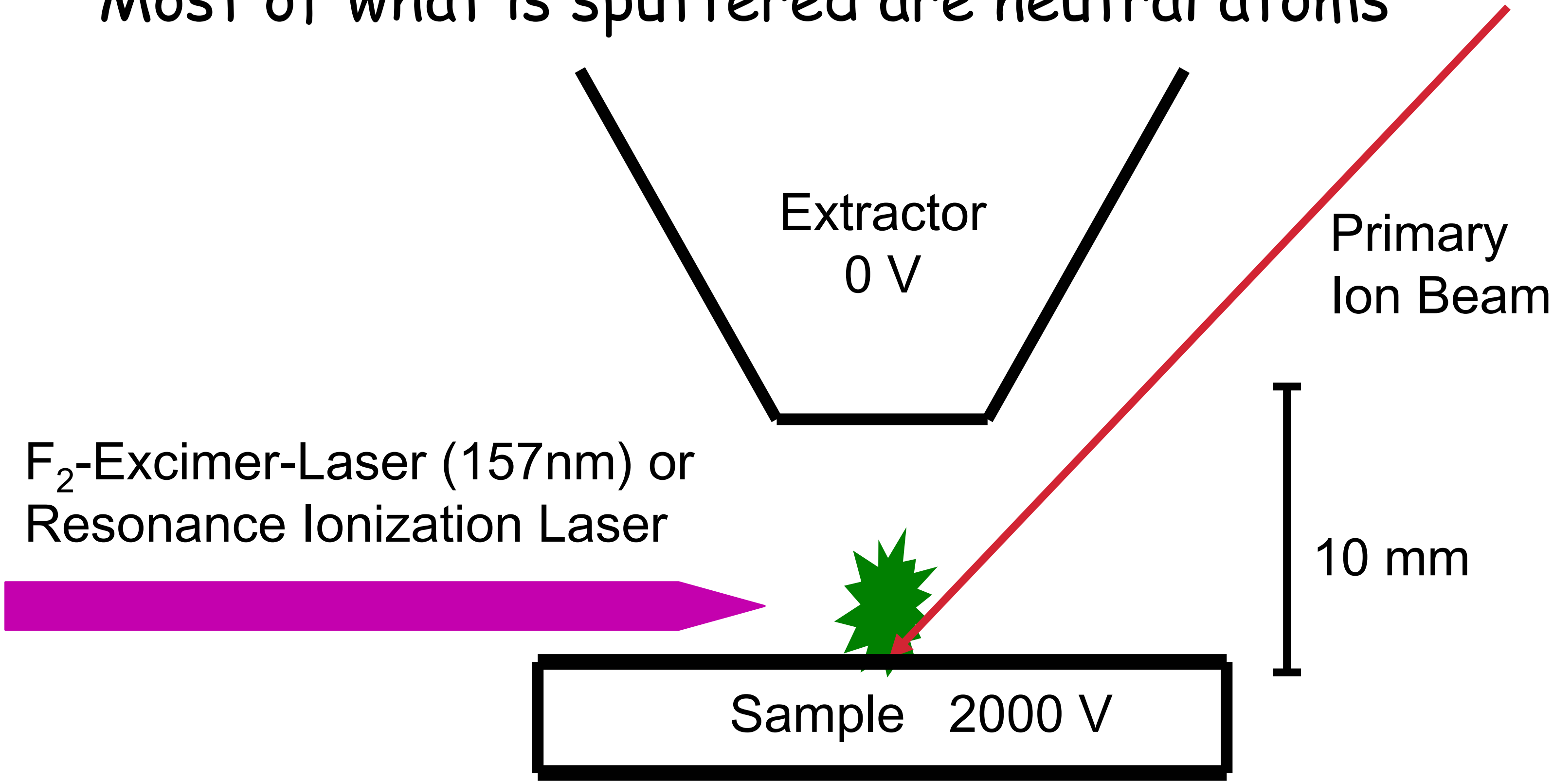
Overcoming the SIMS Limit

Ionization probabilities in SIMS are fixed.

Most of what is sputtered are neutral atoms



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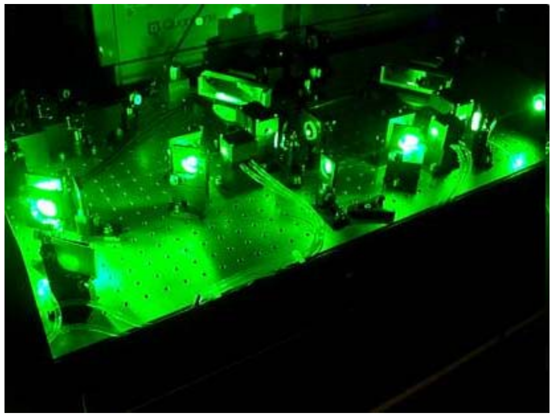
Overcoming the SIMS Limit

Ionization probabilities of up to ~1 can be achieved Major problem is achieving spatial and temporal overlap between the laser beam and the sputtered neutral atom plume.

Resonance Ionization – tuned lasers selectively ionize chosen element – no isobaric interferences



Argonne National Lab CHARISMA, SARISA

Total efficiency 10-100%, Ca, Mo, Zr, Fe, Ru (from extinct Tc)
Have been achieved from single interstellar grains

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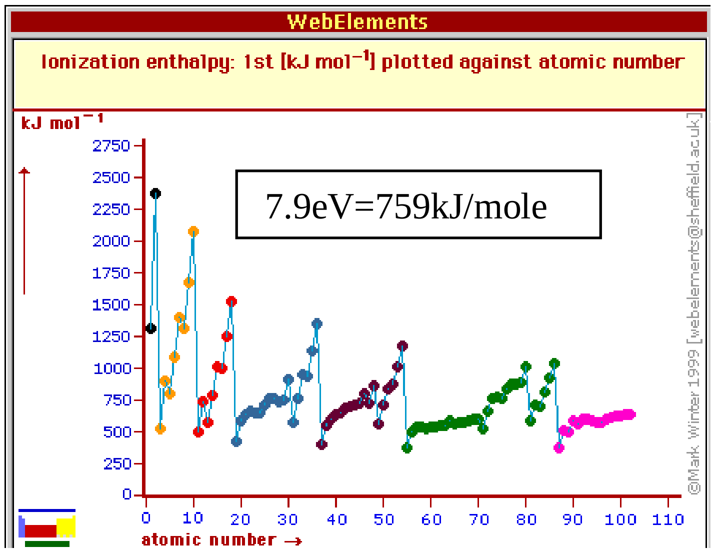
Overcoming the SIMS Limit

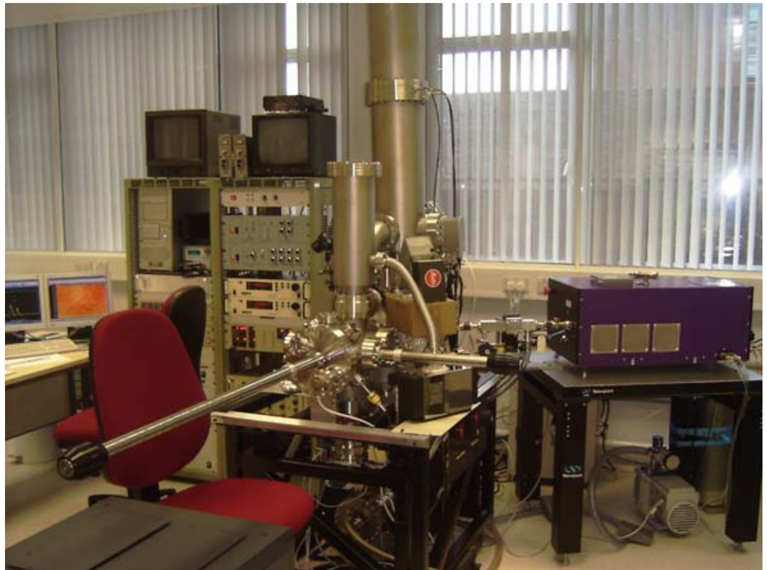
The major advantage of Laser Resonance Ionization
– tuned lasers selectively ionize chosen element

The major problem with Laser Resonance Ionization
– tuned lasers selectively ionize chosen element

Non-selective ionization



Fluorine excimer laser 157nm =7.9eV



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Separation and Preparation of dust grains

To date nearly all presolar grains analyzed have been separated by acid residue treatment

Realization that acids attack surfaces and alter surface properties, may destroy certain morphologies

Finding grains by X-ray mapping (Pristine grains)

Concentrating grains by series of size and density separation steps (gentle separation)

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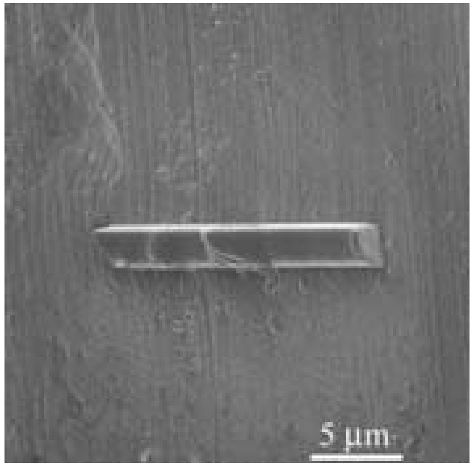
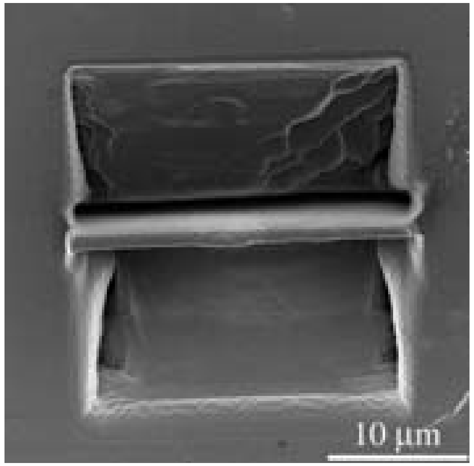
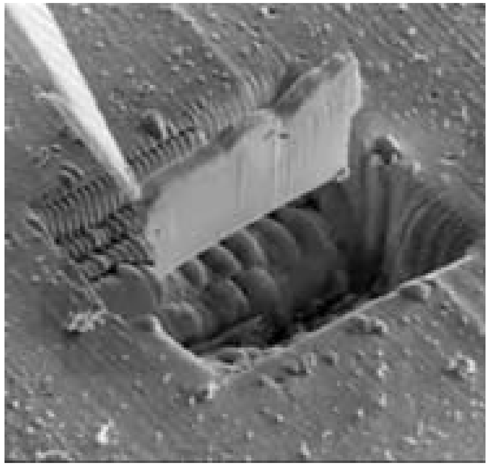
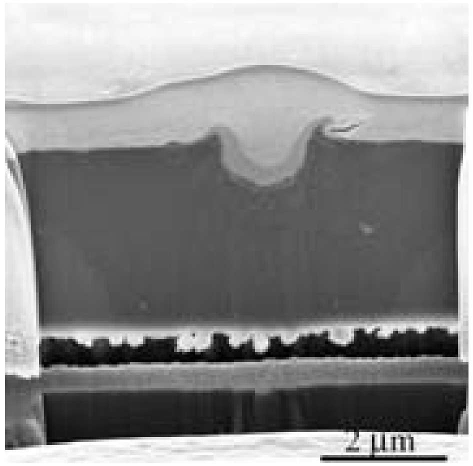
FIB SEM









Leroux

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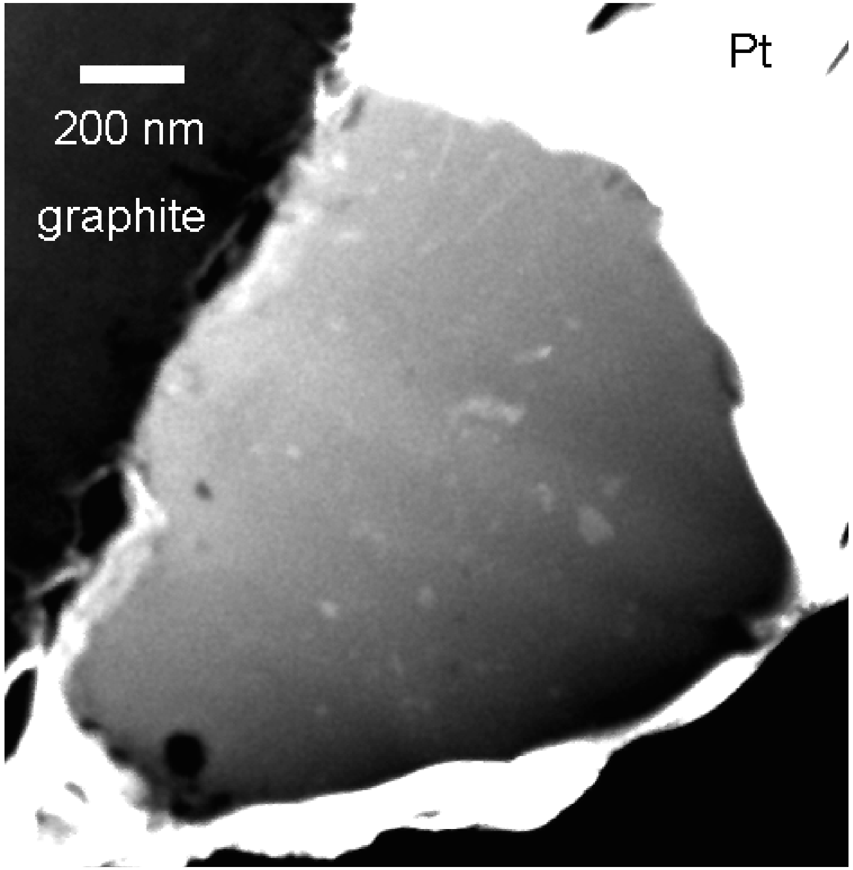
Electron Beam methods

Particularly ATEM methods



Stroud et al.

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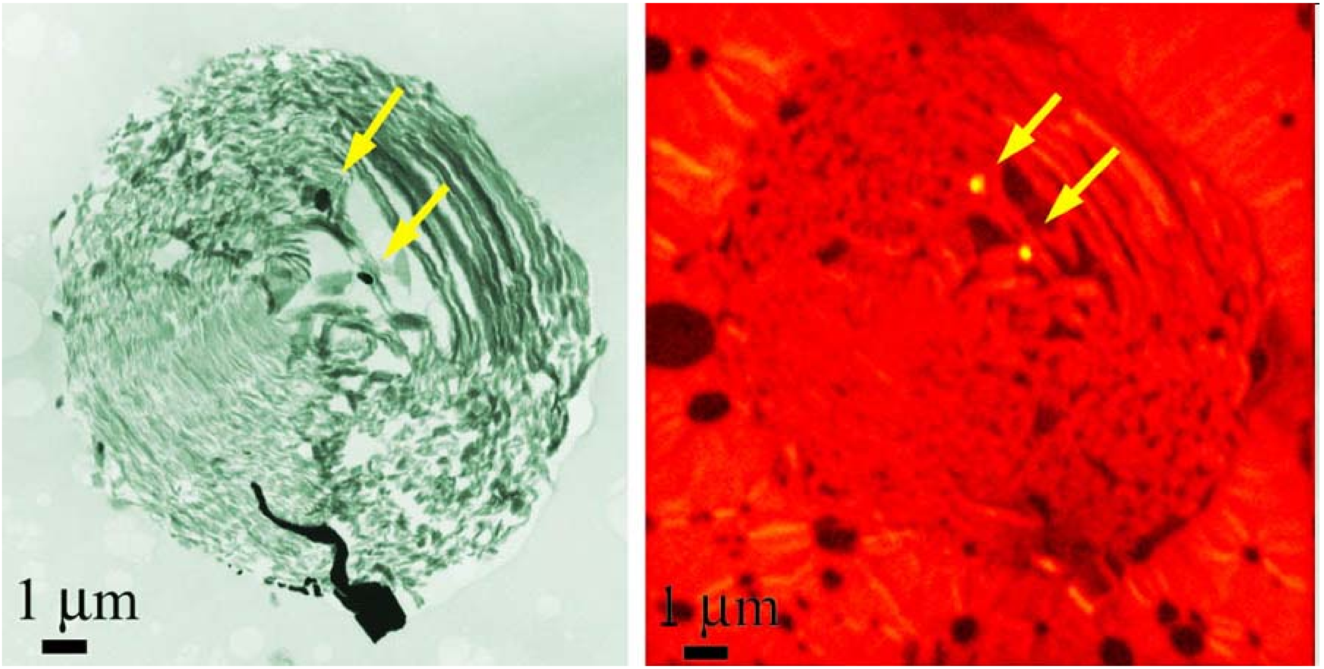
Electron Beam methods

Internal TiC grains within graphite



Washington University St Louis Missouri

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'Nano-Astrophysics'

Can now take slices of micrometer sized grains and study their internal structure

Laboratory Astrophysics is advancing to the point where we can take apart micrometer sized particles and study their 3D morphology, elemental and isotopic compositions

Build up a complete picture which can help reveal their formation, components and modification in the interstellar medium

Not quite there yet – but not too far off!

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