Laser Spectroscopy of Radioactive Isotopes

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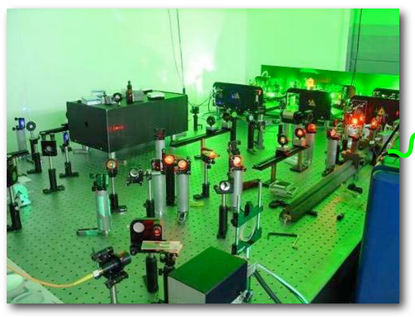
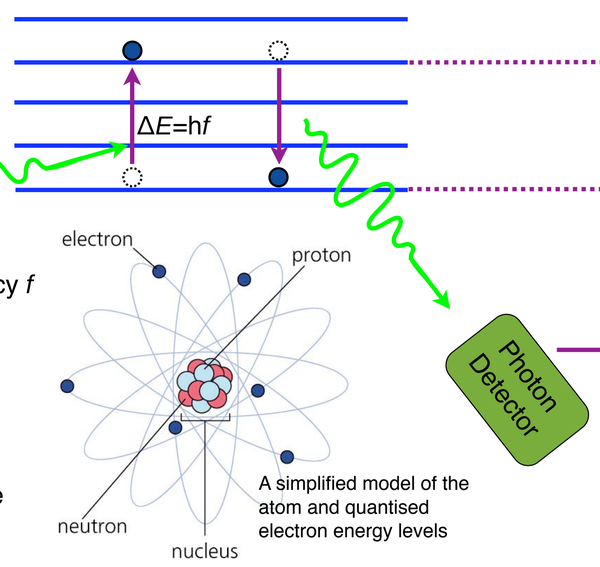
Laser spectroscopy is a fast and sensitive technique used to obtain a variety of nuclear properties. These are used to identify trends and features, to further our understanding of microscopic interactions and bulk properties, and assist in the development of future models of the nucleus. Radioactive nuclei and their excited (metastable, "m") states with lifetimes ranging from stability to sub-millisecond are studied. This collaborative effort is between the Universities of Manchester and Birmingham, working mainly at the IGISOL (Ion-Guide Isotope Separator On-Line) at JYFL, Finland, but also at ISOLDE, CERN.

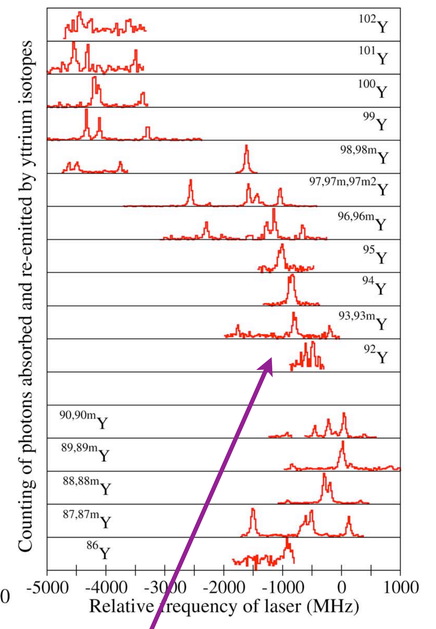
Installation of an ion-beam cooler at ISOLDE, CERN

Introductory Theory



During a laser frequency scan, electrons are excited when a resonance is reached. Photons are absorbed and re-emitted.



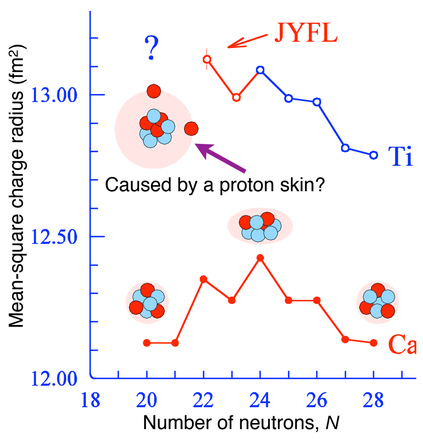


High resolution spectroscopy reveals the splitting of these spectral lines into the *hyperfine* structure, caused by the interaction between the electrons and the nucleus. From this analysis, we can determine nuclear properties such as the magnetic moment, quadrupole moment (shape), and nuclear angular momentum quantum number.

The movement of these structures with the addition of neutrons (or nuclear excitation) allows us to track the changing nuclear **mean-square charge radius,** itself influenced by size, shape (and its time dependence) and diffuseness.

Results

The chart below shows the nuclear landscape. Isotopes coloured in black are stable and radioactive isotopes studied using laser spectroscopy are in red. Three of the areas of current interest to us are indicated.

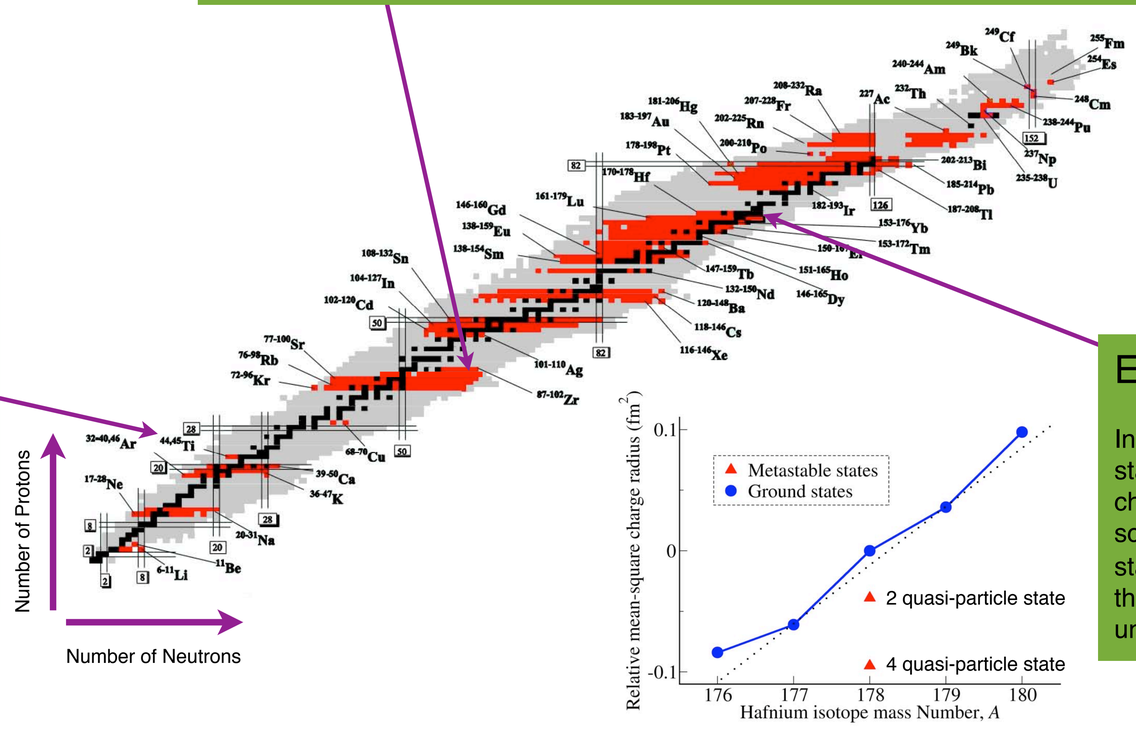


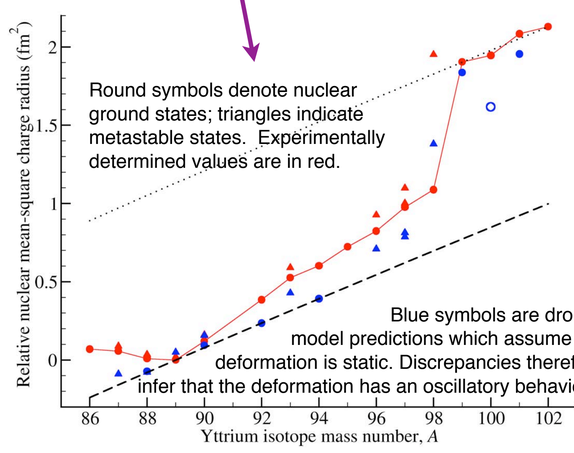
Proton skins

While it is usual for the mean-square charge radius to reach local minima at shell closures, the values for Ca at the shell closures N=20 and N=28 are identical. Experiments by the group have shown charge radii values for Ti continue to *increase* with the *removal* of neutrons.

Sudden onset of deformation with neutron number

Isotopes of yttrium (right) were recently explored to investigate the sudden increase in charge radius at $N \approx 60$ ($A \approx 100$) associated with a sudden onset of deformation. Our studies show that the nuclei go from increasingly oblate (smartie-shaped) to strongly prolate (rugby ball shaped) at this point. Also, the deformation changes from increasingly dynamic in nature, to static, post N = 59.



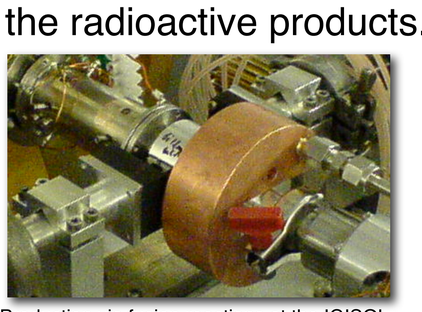


Excited states and odd-even staggering

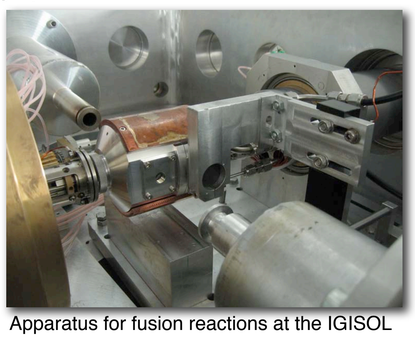
Investigations in Hf, Yb and Y have given examples where metastable states with a number of unpaired nucleons have a *smaller* mean-square charge radius despite an *increase* in deformation. This effect appears to scale with the number of unpaired particles. The odd-N — even-N staggering that can be seen clearly on the left (and far left) is seen also throughout the nuclear chart. While neither of these effects are fully understood at present, they may be related to each other in origin.

Isotope Production and Beam Formation

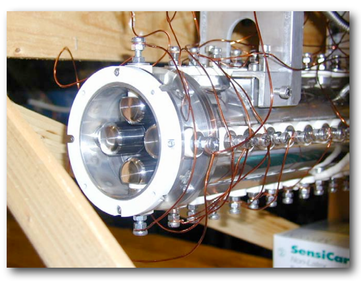
At the IGISOL, the reaction products recoil from thin foil targets and are stopped in a helium gas before extraction. This makes the IGISOL uniquely applicable in cases where fast extraction times are essential due to short half-lives or where the chemistry prevents the release of the radioactive products.



Production via fusion reactions at the IGISOL

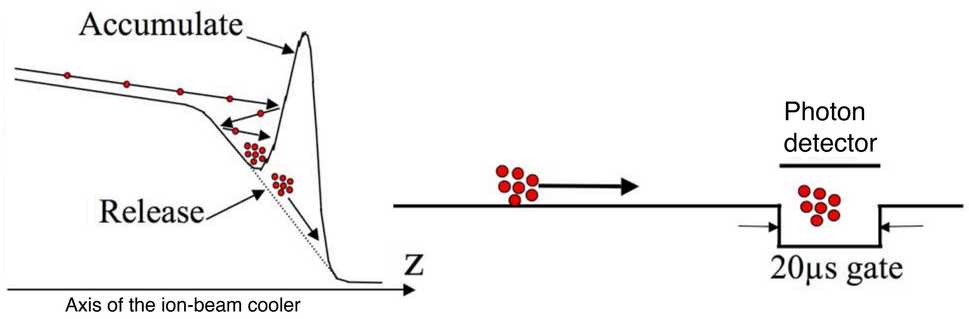


Apparatus for fusion reactions at the IGISOL



Inside an ion-beam cooler

To improve beam quality, the ions are passed through an ion-beam cooler. This reduces the energy spread of the beam and the emittance. The collaboration have pioneered the use of laser spectroscopy on bunched beams. By only counting photons in coincidence with the transit of an ion bunch, the background is reduced by 10,000 times.



Axis of the ion-beam cooler

Sample References: "First On-Line Laser Spectroscopy of Radioisotopes of a Refractory Element", Physical Review Letters **82** (1999) 2476; "On-Line Ion Cooling and Bunching for Collinear Laser Spectroscopy", Physical Review Letters **88** (2002) 094801
"Laser Spectroscopy of Cooled Zirconium Fission Fragments", Physical Review Letters **89** (2002) 082501; "Size matters when testing exotic nuclei", Physics World (2002);
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