1759 ….. An import year !

Some Historic and Current Aspects of Plasma Diagnostics Using Atomic Spectroscopy

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Outline

What do theoreticians calculate

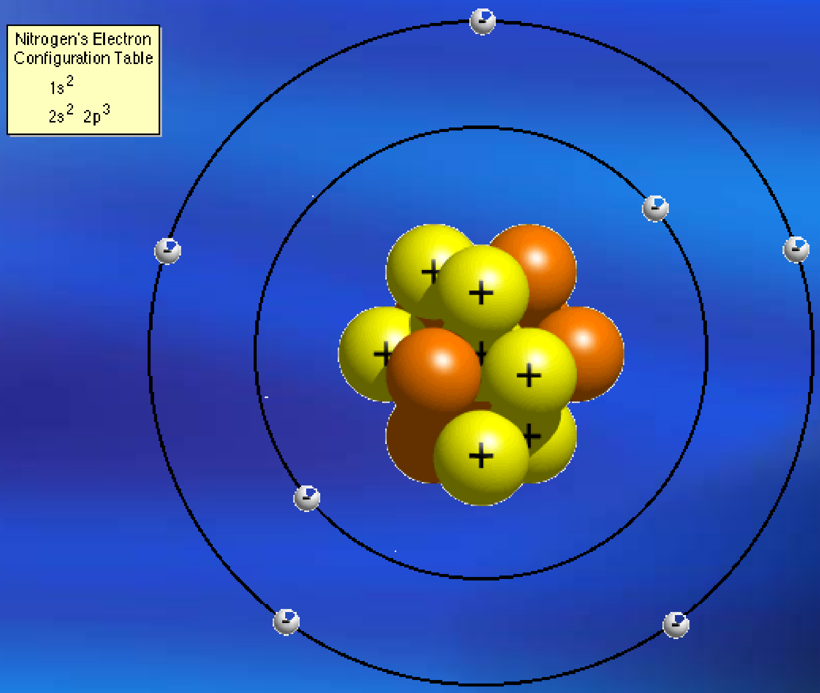
What do experiments measure ?

Basis of plasma diagnostics based on atomic spectroscopy

a little history

Current work and Future outlook

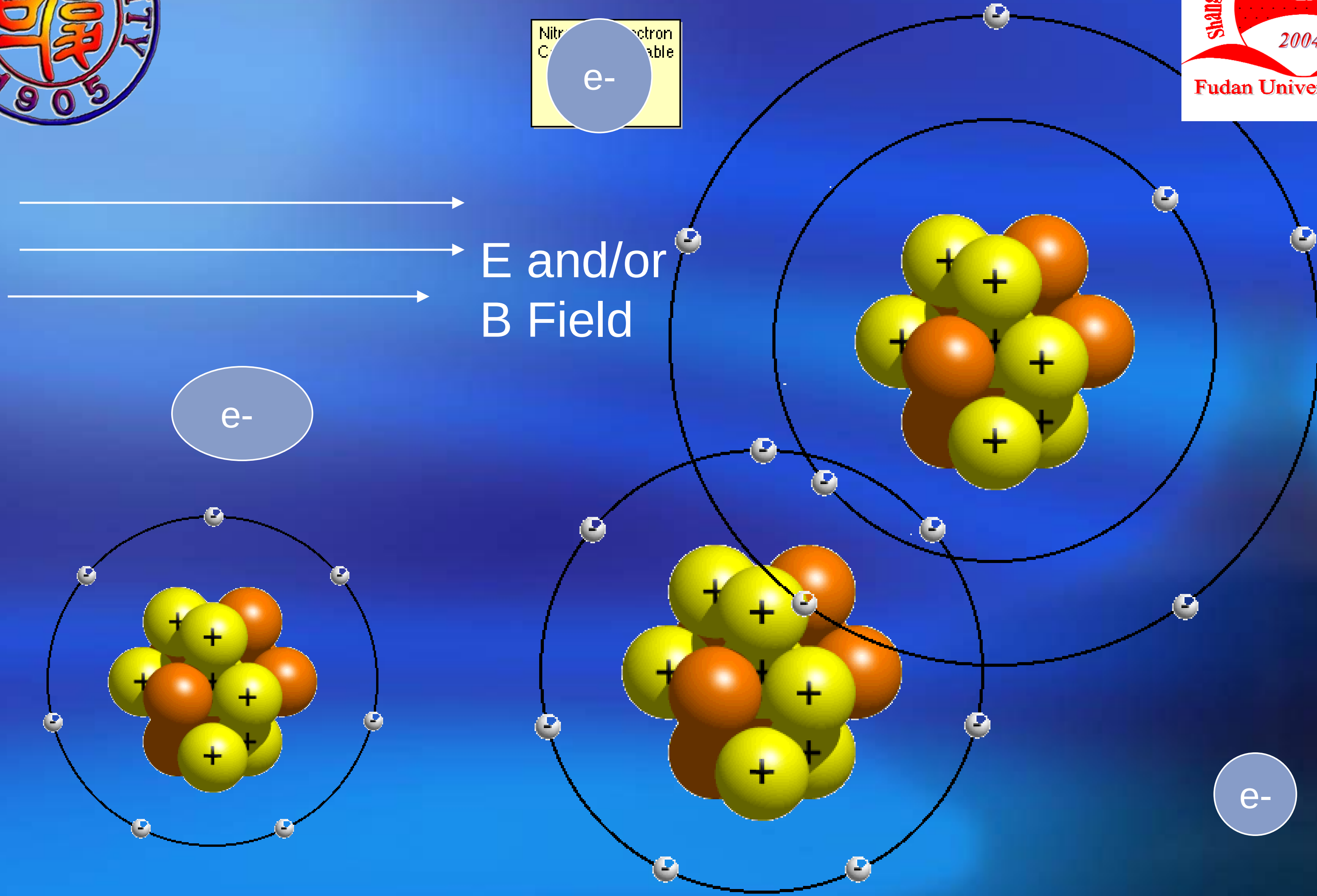
What do atomic structure theoreticians calculate ????



It does not matter what method or code !

Atoms or ions in free space and unperturbed by external fields

What do experiments measure ?



Not in free space and perturbed by external forces !

There is a BIG difference !

This difference is the basis of plasma diagnostics based on atomic spectroscopy

The trick is to find spectral lines that come from levels sensitive to the environment

This most often means that metastable levels are involved and usually a line ratio is used.

Plasma diagnostics via spectroscopy is based on these ideas

A little history, the Solar Corona

First spectroscopic observations were around 1869 (most famous)

The recorded spectra lead to the identification of Helium and a number of other elements ("Coronium" being one).

There is a very strong green line, known as the Corona green line at **5302.86** Å

The famous Corona green line

Observed 1869

Explained in early 1940's as the $^2P_{1/2} - {}^2P_{3/2}$ ground state forbidden transition in Fe XIV (Fe^{13+}).

But this went against contemporary thinking that the sun and the corona had the same temperature.

It was known that the surface temperature of the sun was (still is) around 6000 degrees.

At 6000 degrees there are no highly charged ions, Fe XIV (Fe^{13+}) needs at least 3 million degrees.

The wavelength is 5302.86 Å and the $^2P_{3/2}$ level lifetime is 16.75 ms, measured using an EBIT to an accuracy of better than 1 %.

Ground term forbidden transitions in highly ionized Fe and Ni

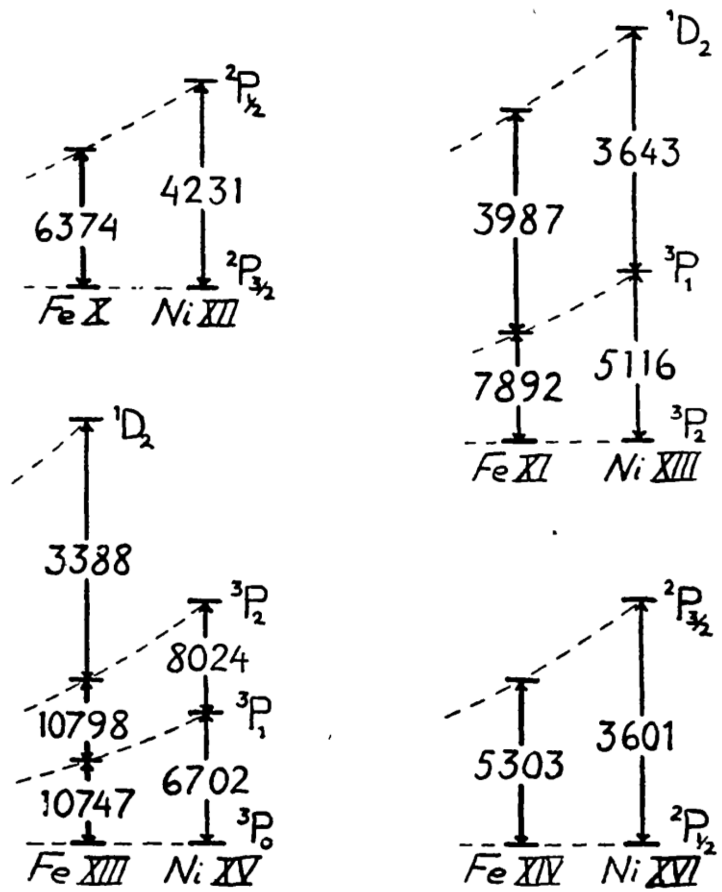
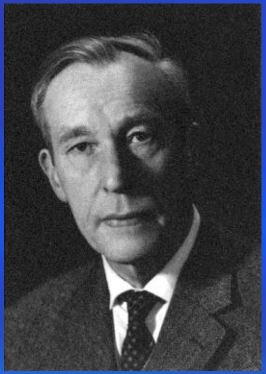


FIG. 4.



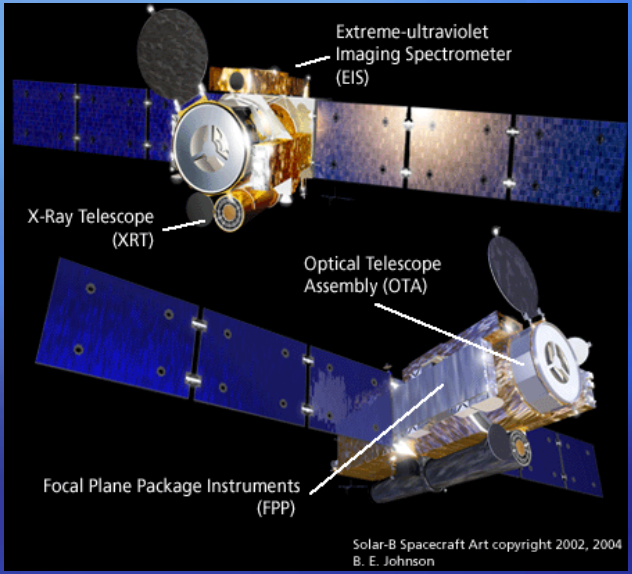
"Fysikum," the department of physics at Uppsala University, in 1908. The annex (right) contained workshop, electrical generators, and research assistant housing. (Photo from Knut Ångström, *Den nya fysiska institutionen vid Uppsala universitet*, reprint from *Upsala Nya Tidning*, (Uppsala, 1909))

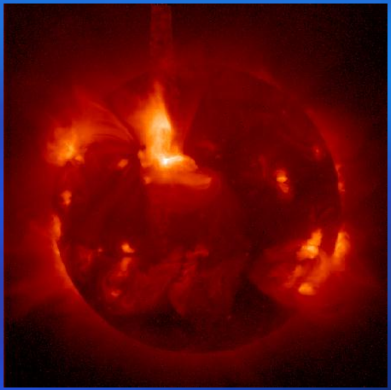
"Jag trodde inte att dom fanns någon annonstans på den blåa himlen eller på den gröna jorden"

Bengt Edlén

What about now ?

Hinode (日の出) or Solar B





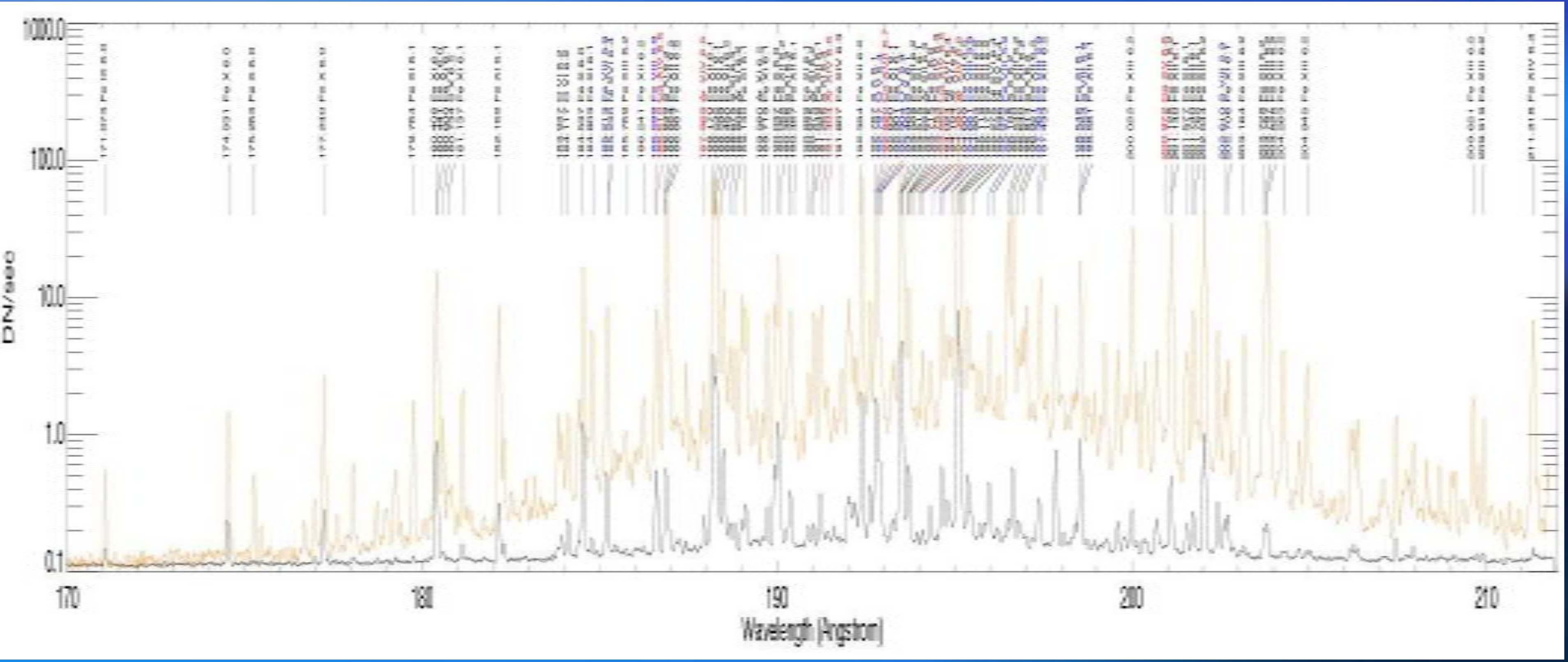
Hinode's overall goals are:

(1) to understand how energy generated by magnetic-field changes in the lower solar atmosphere (photosphere) is transmitted to the upper solar atmosphere (corona),

(2) to understand how that energy influences the dynamics and structure of that upper atmosphere, and

(3) to determine how the energy transfer and atmospheric dynamics affects the interplanetary-space environment.

Part of a spectrum of our sun, taken using the spectrometer onboard Hinode and covering the wavelength region of 17 – 21 nm, a spectral region not possible to observe from the earth.



Important discoveries in Tokamak

fusion diagnostics using atomic spectroscopy

Plasma impurities can be classed as a landmark finding !

In 1978 forbidden M1 transitions in highly ionized Fe XX were observed in the Princeton tokamak.

In this work the authors could determine the ion temperature to be around 45 million degrees K.

Densities, Temperatures and Plasma Impurities can be studied

Why was the discovery of impurities so important for the fusion program ?

Two things !

1) ***The impurity lines can be used to great advantage to measure the plasma temperature and density.***

2) ***We need to know the concentration of the impurities as heavy elements tend to be very good at turning heating energy into wasted radiation !***

Aside, the Tokamak became an important light source for spectroscopic studies !

Houses of Parliament in London, which contains a part called the House of Lords.

Science and the normal person ...

Viscount Davidson: *My Lords, though much remains to be done, the latest results from JET have been encouraging. A temperature of 140 million degrees centigrade has been reached. ...*

...

The Earl of Lauderdale: *My Lords, can my noble friend add to what he said about the progress of the JET project when he referred to a temperature of 140 million degrees centigrade having been attained? Can he say whether that has yet exceeded a duration of one-hundredth of a second?*

Viscount Davidson: *No, my Lords,*

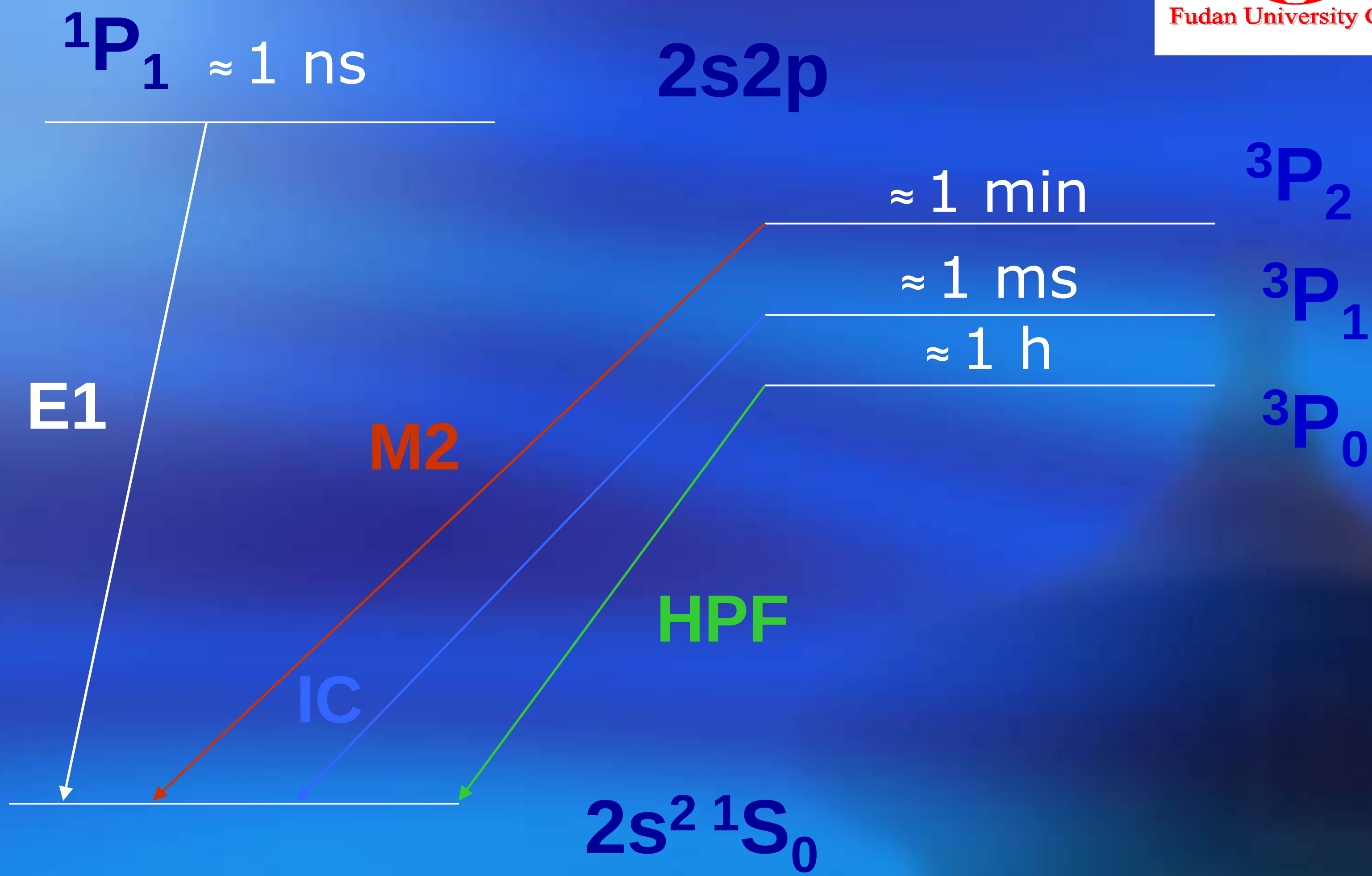
...

Earl Ferrers: *My Lords, what kind of thermometer reads a temperature of 140 million degrees centigrade without melting?*

Viscount Davidson: *My Lords, I should think a rather large one.*

Hansard, 19th March 1987, (1517-9)

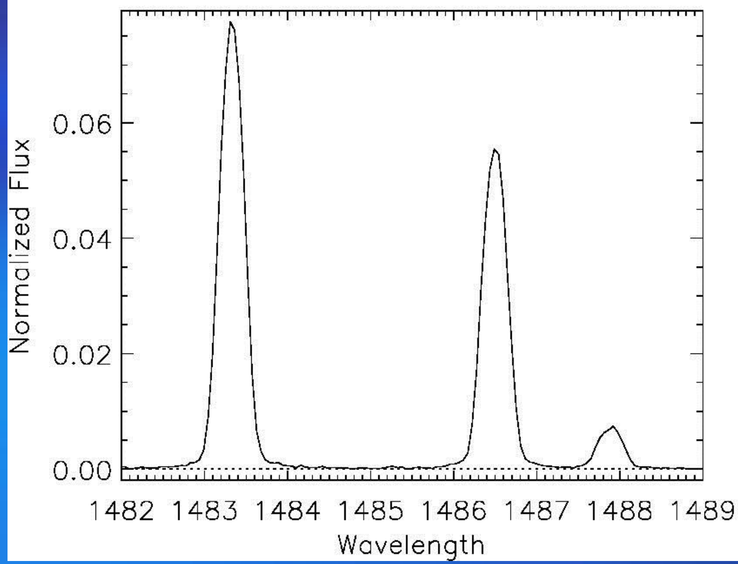
The atomic structure of Beryllium-like N IV



The smaller of the three lines can be identified as the hyperfine induced decay

From Brage, Judge and Proffitt, PRL 89, 281101 (2002)

planetary nebula NGC3918



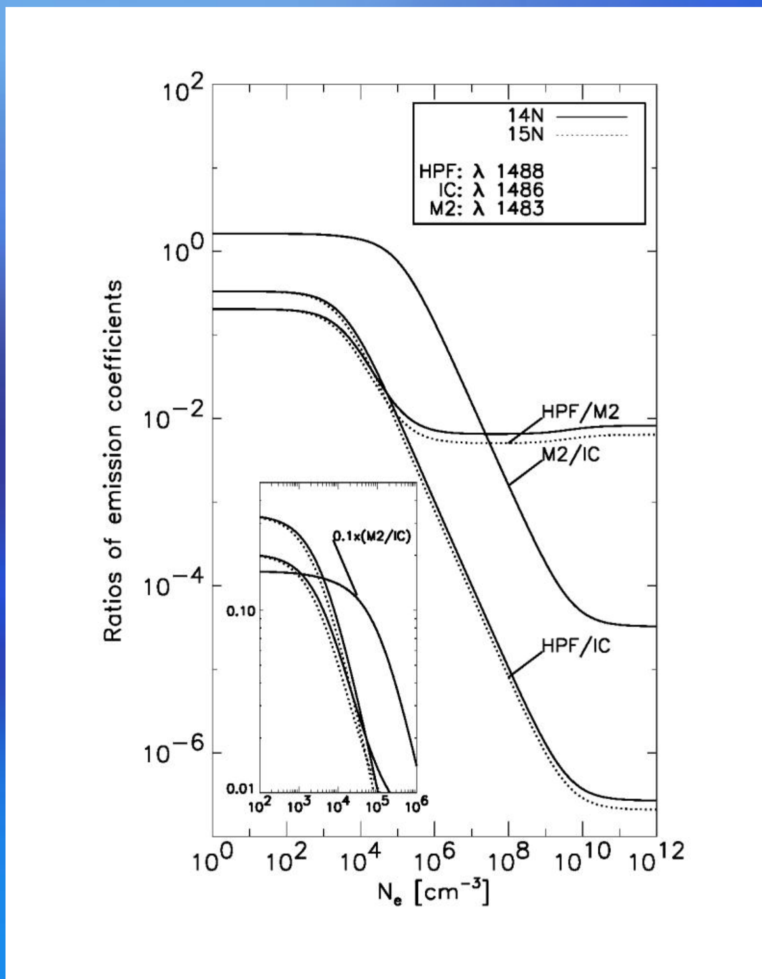
$^3P_0$ lifetime

The lifetime of the 2s2p $^3P_0$ level was determined to be around 11 hours.

This is by far the longest atomic lifetime ever determined, for storage ring experiments the longest lifetime measured is around 1 minute.

Such long lifetimes cannot be measured with EBIT techniques, for lifetimes around 1s EBIT would need a very high vacuum and hence a very small signal !

Electron density diagnostics using Be-like nitrogen lines



This shows the sensitivity of line ratios for transitions from levels of the 2s2p ^{3}P term to the 2s^2 ^{1}S$_0$ ground state for Be-like N, as a function of electron density

Brage et al., Astrophys. J. **500**, 507 (1998).

Forbidden lines and nuclear effects

Ni-like xenon

E. Träbert et al., Phys. Rev. **A 73**, 022508 (2006)

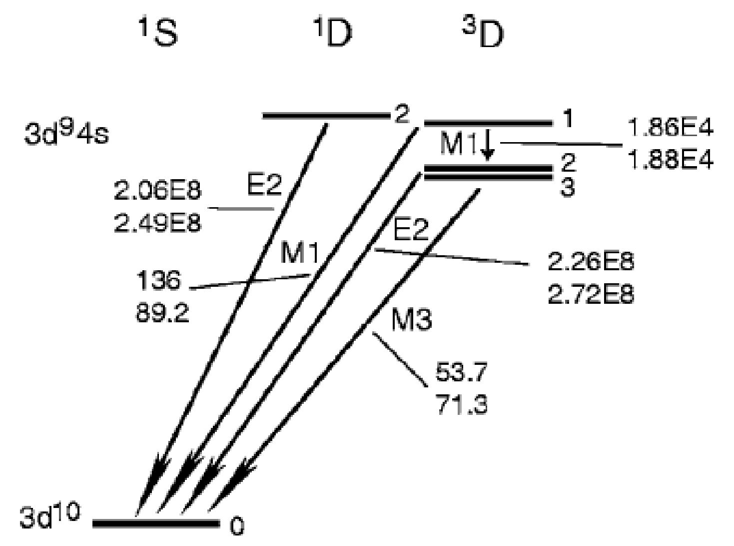


FIG. 1. Lowest levels and principal decays in Ni-like ions. The J values of the levels are noted at the right end of the level bars. The numbers associated with the principal decays are the calculated transition probabilities A_{ki} in the format aEb meaning $a \times 10^b$ s^{-1}. The first of each entry is from calculations by Safronova *et al.* [22,23], the second from our own GRASP code calulations (see text).

Magnetic Octupole lifetime in Ni-like Xe, Ce and Ba

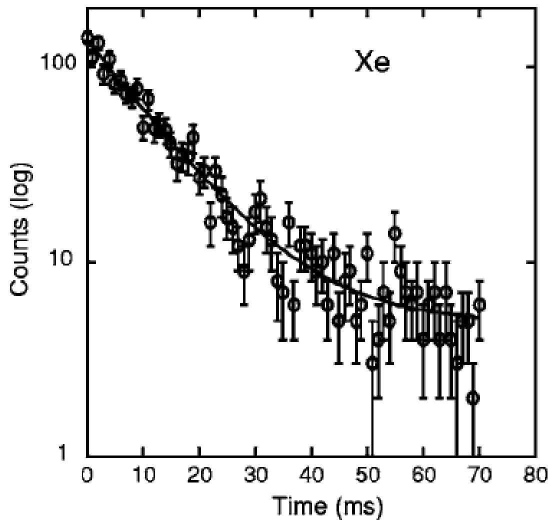


FIG. 7. Decay of the $M3$ line [from Fig. 6(a)]. The solid line represents a single exponential (plus background) fitted to the data.

Decay curve for the M3 decay in Ni-like Xe, measured using the LLNL EBIT.

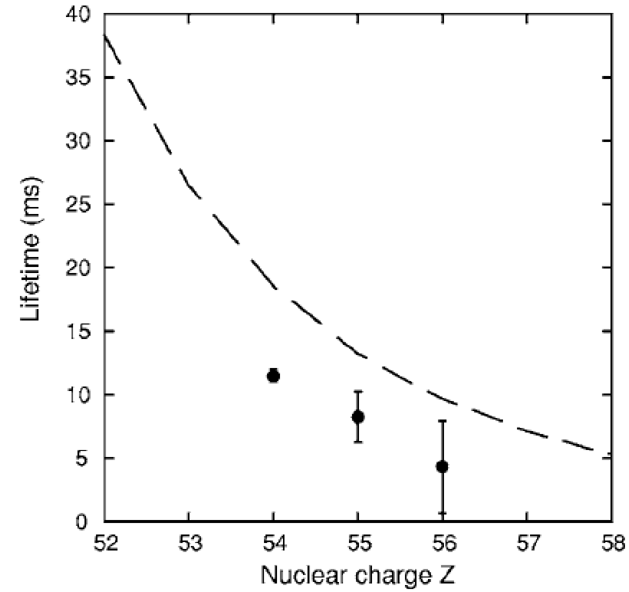
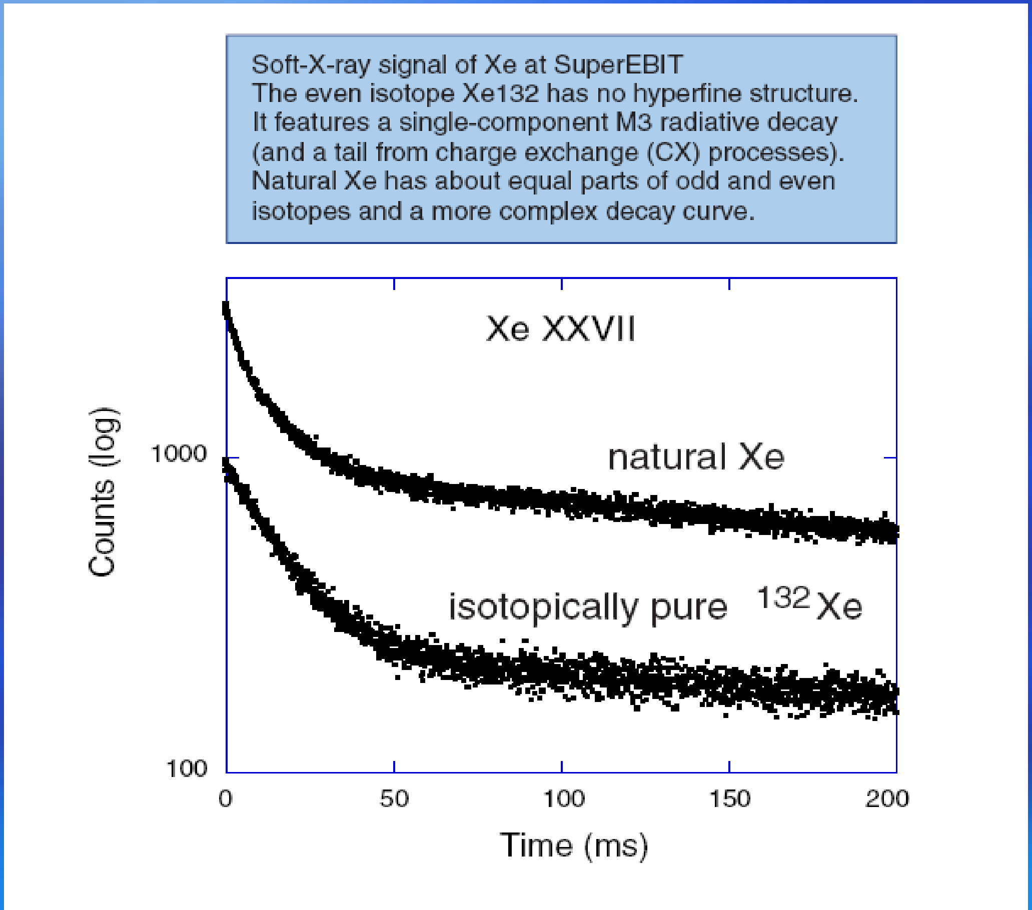


FIG. 8. Lifetime of the $3d^9 4s\ ^3D_3$ level as predicted by Safronova *et al.* [22,23] (dashed line) in comparison with our measurements for Xe, Cs, and Ba.

Experimental and theoretical life-times for the M3 decay

The experimental determined M3 lifetimes disagreed with the theoretical results

Isotope resolved studies



M3 decay curves in Ni-like Xe

natural Xe and isotope pure ^{132}Xe

^{132}Xe only one component as there is no nuclear spin.

The "bottom line" of this work if that lifetimes are f dependent !

Hyperfine induced mixing

TABLE I: Contributions to the F-dependent rates A(s^{-1}) for the $3d^{10}\ {}^1S_0(F_f = I)$ - "$3d^9 4s\ {}^3D_3(F_i)$" transitions and final lifetimes of "${}^3D_3$" sublevels of Xe^{26+}.

isotope	I	F_i	A(M3)	ϵ^2A(E2)	A(tot)	τ(ms)
Xe	0	—	66.15	0.0	66.15	15.12
^{129}Xe	1/2	7/2	66.15	0.0	66.15	15.12
		5/2	66.15	286.34	352.49	2.84
^{131}Xe	3/2	9/2	66.15	0.0	66.15	15.12
		7/2	66.15	96.36	162.51	6.15
		5/2	66.15	92.53	158.68	6.30
		3/2	66.15	45.95	112.10	8.92
Fitted Lifetime (ms):			(I)10.85,	(II)11.38,	(III)11.83	
Exp.[2]					87 ± 4	11.5±0.5
Theo.[2]			71.30			14.03
Theo.[3]			53.70			18.62

Hyperfine interaction induces mixing between the $^3D_3$ and $^3D_2$ levels

Hence the $^3D_3$ is shortened compared to what is would have been

M$_F$-Dependent Life Time Due to Hyperfine Induced Interference Effect

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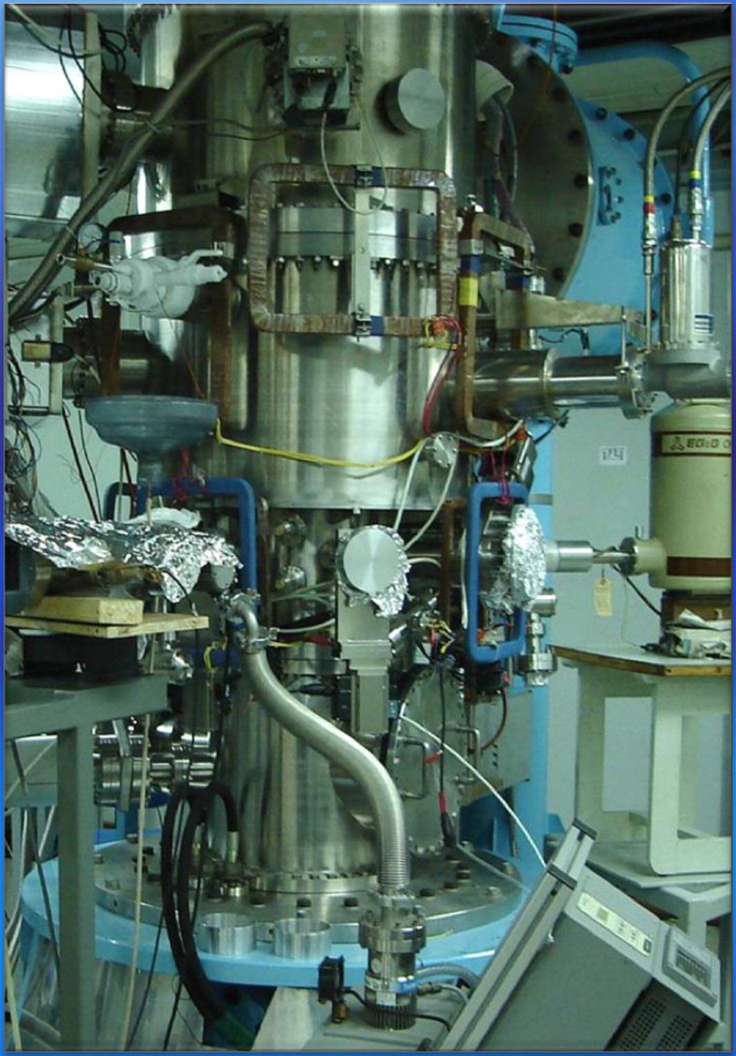
What are we doing ?

The Shanghai Electron Beam Ion Traps, EBITs

High energy EBIT (11 – 2200 Million degrees)



Low energy EBIT (0.66 – 55 Million degrees) DESK TOP PHYSICS !

Here you can see two of the spectrometers for viewing the hot plasma. One covers the region of 5 – 25 nm (covering the range of the Hinode spectrometer) and the other is for the 250 – 600 nm range (i.e. ultra violet – visible)

Conclusions

1) Diagnostics using atomic spectroscopy

Spectroscopy has made some important contributions to the study and diagnostics of hot plasmas, things studied so far include

(1)Composition

(2)Temperature

(3)Density

Future possibilities, local magnetic field strength, even more density sensitive lines ….

Collaborators:

Many, as you will see in a later slide and also

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谢 谢

Thank you for your attention !