Plasma Diagnostics Employing Spectra of Helium-like ions

H.-J. Kunze
Ruhr-University Bochum, Germany

Atomic physics, plasma spectroscopy, and solar physics from space:
Celebrating the achievements of Alan Gabriel

Institut d'Astrophysique Spatiale, CNRS-Université Paris-Sud
Orsay, France, 20 June 2013

1965/1966 H.-J. Kunze at the University of Maryland, College Park, on leave from the Institute for Plasma Physics in Garching to Hans Griem, had built a large-bore theta pinch for spectroscopic studies

1966 Return to Germany was not possible

because

pinch was running too well *and*
Alan Gabriel (then Culham Laboratory) joined for a year

Combination of experience

A: Experience in spectroscopy

H-J: Experience in Thomson scattering with lasers
(Radially resolved $n_e(t)$ and $T_e(t)$)

We both spent all day long together in the lab and enjoyed this very much

We had two very simple instruments which Hans Griem had acquired from Heroux and the Naval Research Laboaratory
A scanning grazing incidence spectrometer and a scanning Bragg-crystal instrument
They were designed for use in rockets and we had to adapt them to laboratory use

We focused on the spectrum helium-like ions and selected CV in the UV and the grazing incidence region *and* OVII in the soft x-ray region with the crystal spectrometer

In the following graph: Scan of OVII at a certain time for a measured density and temperature

Reproducibility of each discharge was important

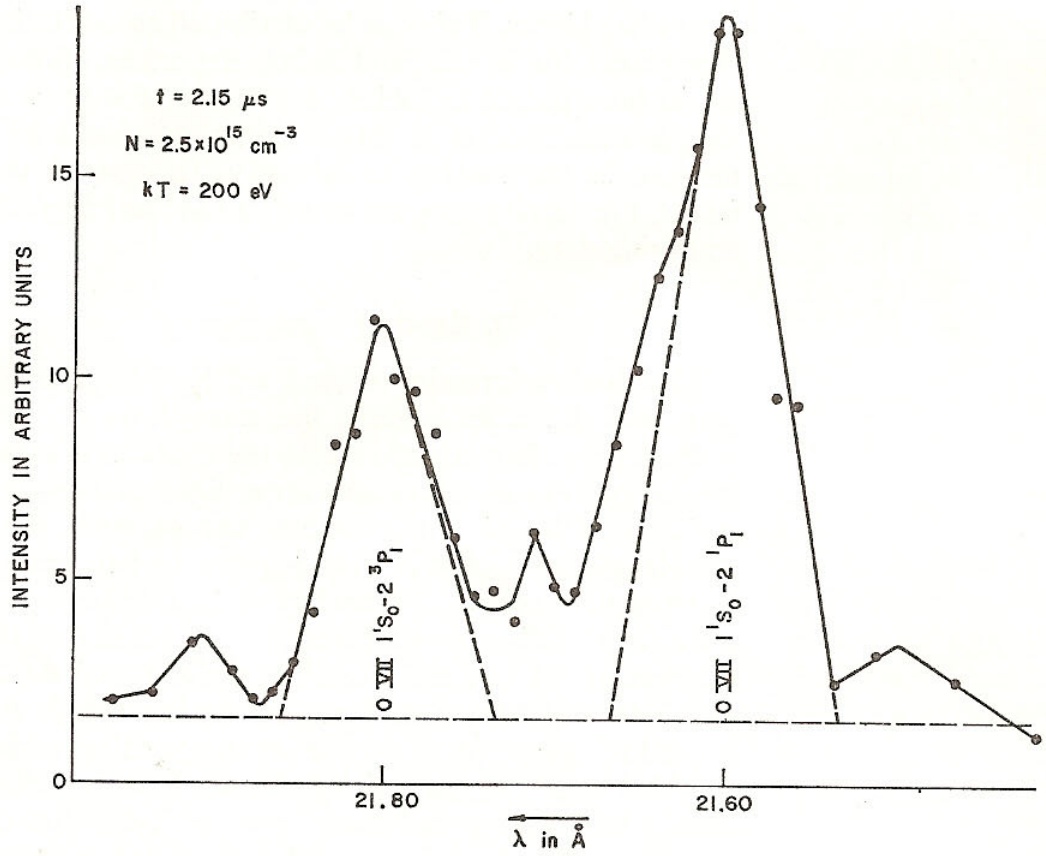


FIG. 4. A scan through the O VII resonance and intercombination lines recorded with the KAP crystal spectrometer.

At that time we were interested in the intensities of resonance and intercombination line

We saw the other weak lines and Alan always said he will study these satellites when he returns home

The analysis of CV (absolute intensities of the triplet lines, relative intensities of resonance to intercombination line, time evolution of the lines

yielded collisional rates for

excitation of the resonance line
exchange between n=2 singlet and triplet levels
ionization from the ground state and
ionization from the n=2 triplet levels

H.-J. Kunze, A.H. Gabriel, H.R. Griem: Phys. Rev. **165**, 267 (1968)

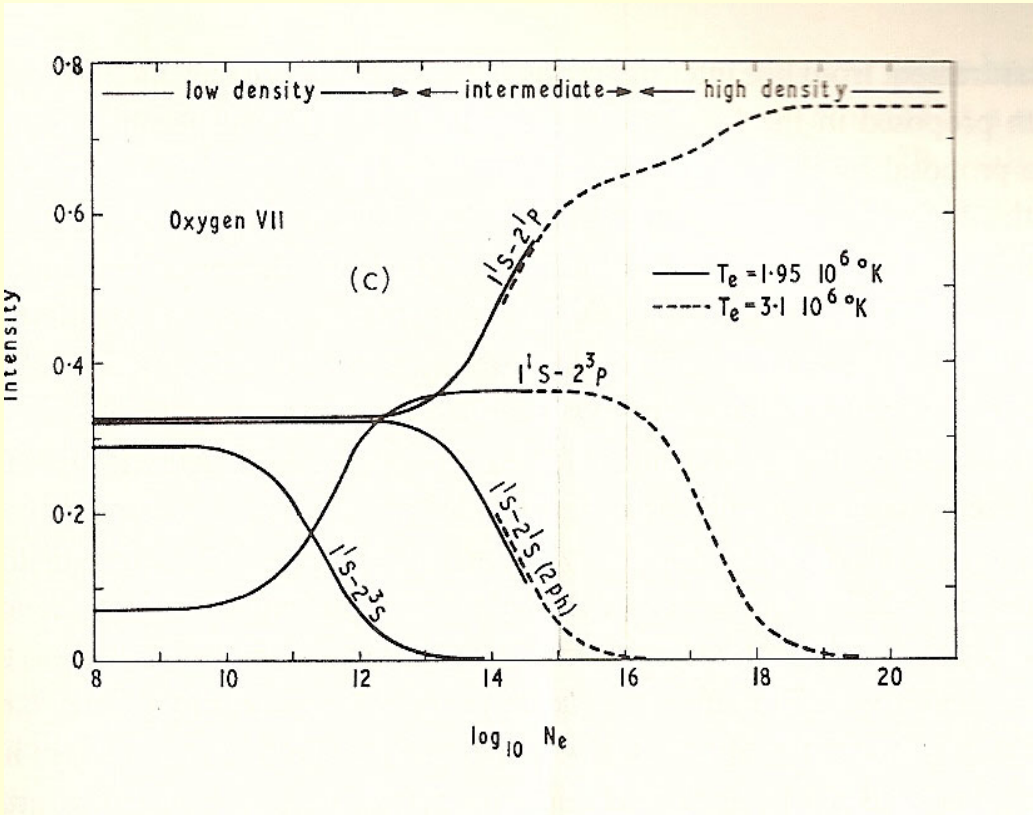
In the inverse direction n_e and T_e can be determined from the transient observation of the helium-like ion emission

H.-J. Kunze, A. H. Gabriel, and H.R. Griem, Phys. Fluids **11**, 662 (1968)

The ratio method for the density was first discussed by Griffin and Peacock 1966

After his return to Reading with his family he returned to Maryland for a brief visit in the fall of 1967, and you see him below in the Dumbarton Okas Gardens in Georgetown, Washington DC

Many laboratory groups used the ratio method especially on laser-produced plasmas and micro-pinches: it is convenient since no sensitivity calibration is necessary, lines are close-by! To include astrophysical plasmas it was extended to very low densities.



A. H. Gabriel , Carole Jordan
in
Case Studies in Atomic Collision Physics, Vol. 2,
Ed. McDaniel and McDowell
North Holland 1972,
Chapter 4

for

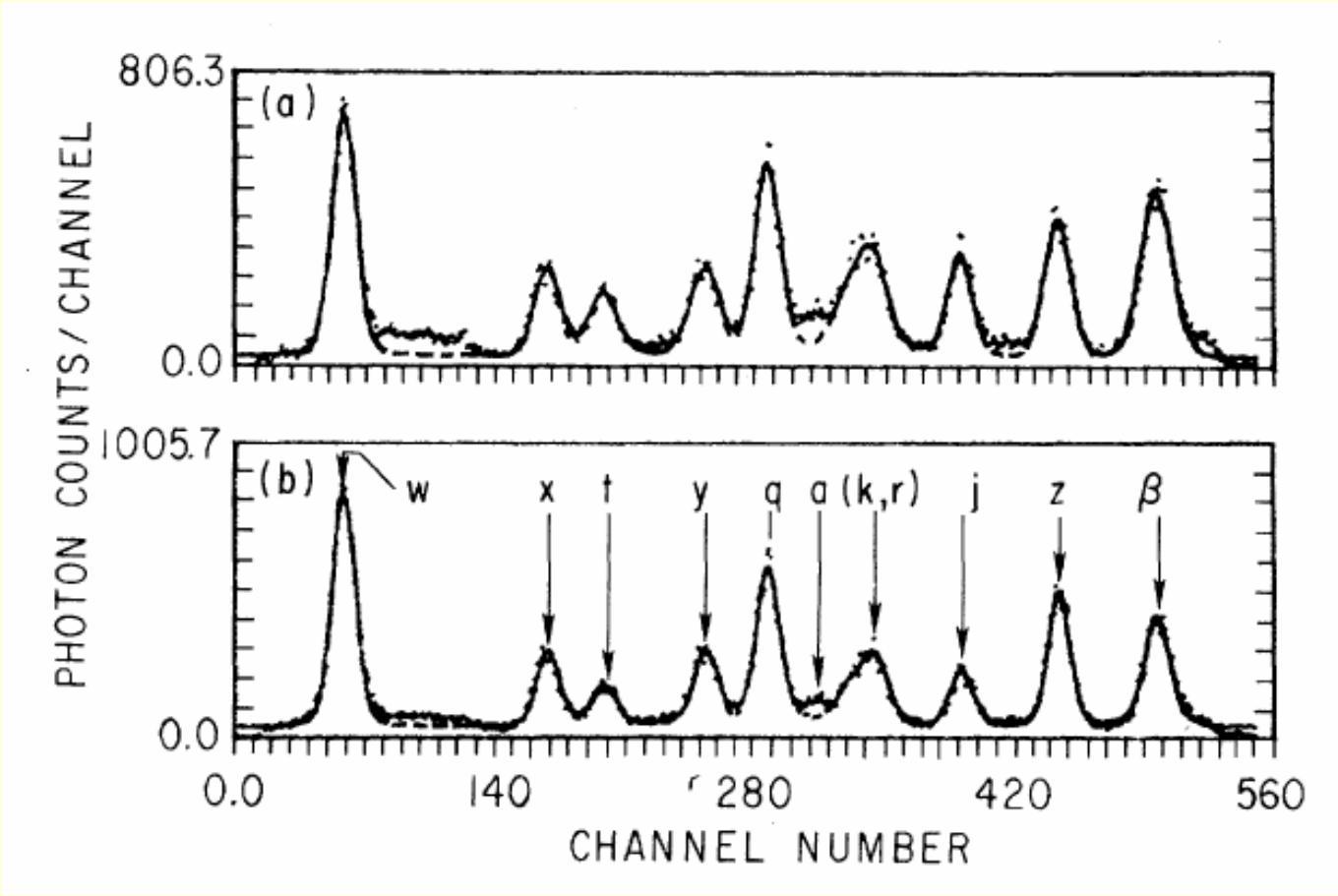
CV to NeIX

In the meantime Alan had started his pioneering work on the satellite lines,
which brought great advances and lead to the present-day applications in fusion plasmas.

Alan and Carole Jordan classified the laboratory satellites,
Nature **221**, 947 (1969)
and
together with T.M. Paget he studied and explained
intensity ratios of satellites and resonance line,
J. Phys. B: Atom. Molec. Phys. **5**, 673 (1972)

I jump his many contributions to solar physics
(all experts are this room).

His ideas and concepts came fully to bear again with the
first spectra of FeXXV obtained from the Princeton Tokamak
(M. Bitter et al., Phys. Rev. Lett. **43**, 129 (1979)



Dielectronic satellite spectra of FeXXV from PLT plasmas with electron temperatures of 1.65 keV (a) and 2.30 keV (b). The points represent the measurements and the solid curves are the theoretical spectra. The lines are labeled according to the nomenclature of Gabriel

! Single shot spectra recorded with a Bragg curved-crystal spectrometer and and a multi-wire proportional counter

In the meantime such high-resolution spectra have been recorded for a number of ions from many fusion plasmas, and are used for diagnostics.

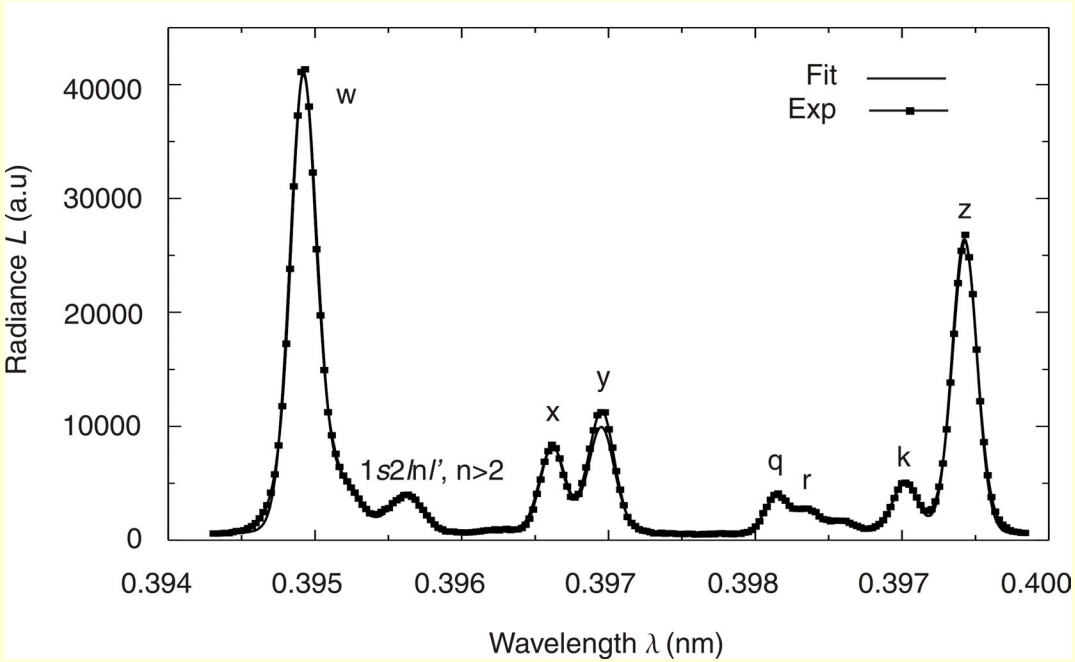
A respective system is planned for ITER.

The above first theoretical spectrum still employed adjustment factors for individual lines to achieve the above agreement with the experiment.

Today, the knowledge of the processes involved and the rate coefficients are far improved, that very good agreement is reached without any fudge factors.

Example:

Next page He-Like Ar from tokamak TEXTOR,
O. Marchuk et al., J. Phys. B **40**, 4403 (2007)



Ratios

$$\frac{\varepsilon_{sat}^{dr}}{\varepsilon_w} = F_1(T_e) \qquad (k-\text{sat})$$

$$\frac{\varepsilon_{sat}^{in}}{\varepsilon_w} \propto F_2(T_e)\frac{n_{Li}}{n_{He}} \qquad (q,r-sat)$$

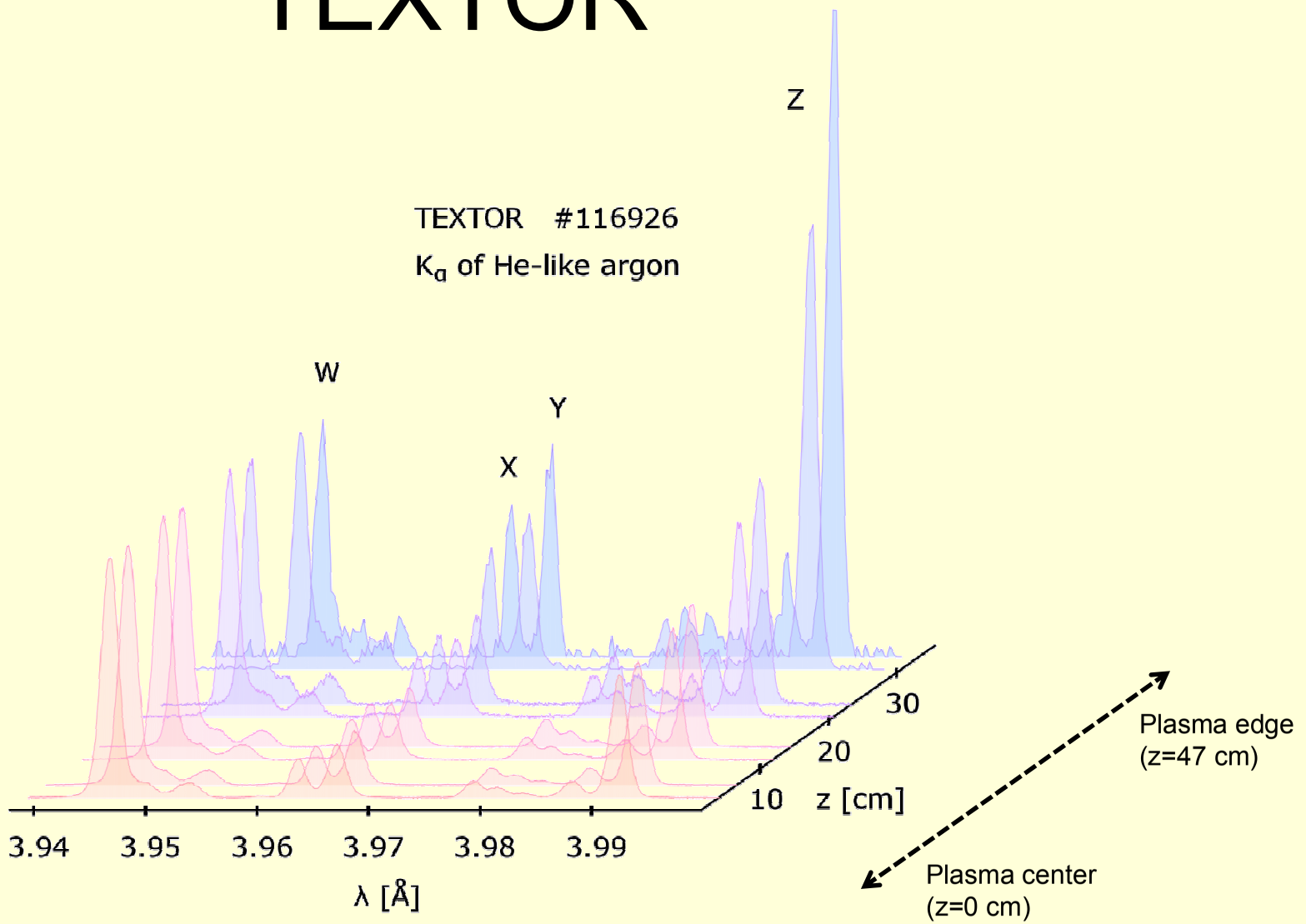
$$\frac{\varepsilon_z}{\varepsilon_w} \propto F_3(T_e)\frac{n_H}{n_{He}} \qquad (z-\text{line})$$

Influence of charge exchange in neutral beam heated plasmas and radial transport is also seen on specific lines

***Present state of the art*:**

Imaging spherically–bent crystal spectrographs and two-dimensional detectors → spatially resolved spectra

K_α-spectrum of He-like argon in TEXTOR



[T. Schlummer, O. Marchuk, G. Bertschinger]