Dielectronic Satellite Lines
Alan Gabriel's work extended

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

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X-ray dielectronic satellite spectra: Gabriel (1972)

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DIELECTRONIC SATELLITE SPECTRA FOR HIGHLY-CHARGED HELIUM-LIKE ION LINES

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SUMMARY

Calculations have been carried out in intermediate coupling of the wavelengths and intensities of the satellite lines situated on the long wavelength side of the helium-like ion resonance lines, recently observed from solar flares. Earlier calculations up to aluminium have been extended up to iron and copper. For the intensities, the important processes are primarily dielectronic recombination, but also direct inner-shell excitation. Comparisons have been made with spectra from solar flares and active regions, and from low-inductance laboratory sparks. Computed wavelengths in iron are found to agree with these to better than 0·0003 Å. Comparison of the intensities allows the determination of both the electron temperature and the transient ionizing state of the plasma. The laboratory plasma spectra are found to be in an extreme transient ionizing condition, and are thus significantly different from solar spectra. In the cases studied, solar active regions were found to be moderately ionizing, while the flare spectra were recombining.

1. INTRODUCTION

Satellite lines situated on the long-wavelength side of helium-like resonance lines were first reported from laboratory spark sources by Edlén & Tyrén (1939), who assigned configurations

$$1s^2nl - 1s2pnl.$$

Dielectronic satellites as diagnostics of flare & fusion plasmas

Equation (7) of Gabriel (1972) was:

$$\frac{I_s}{I} = \underbrace{\frac{0{\cdot}01104}{(1+\alpha)}\frac{E_0}{T}\exp\left[(E_0-E_s)/kT\right]}\times\underbrace{\frac{g_s A_r A_a}{(A_a+\sum A_r)}}$$

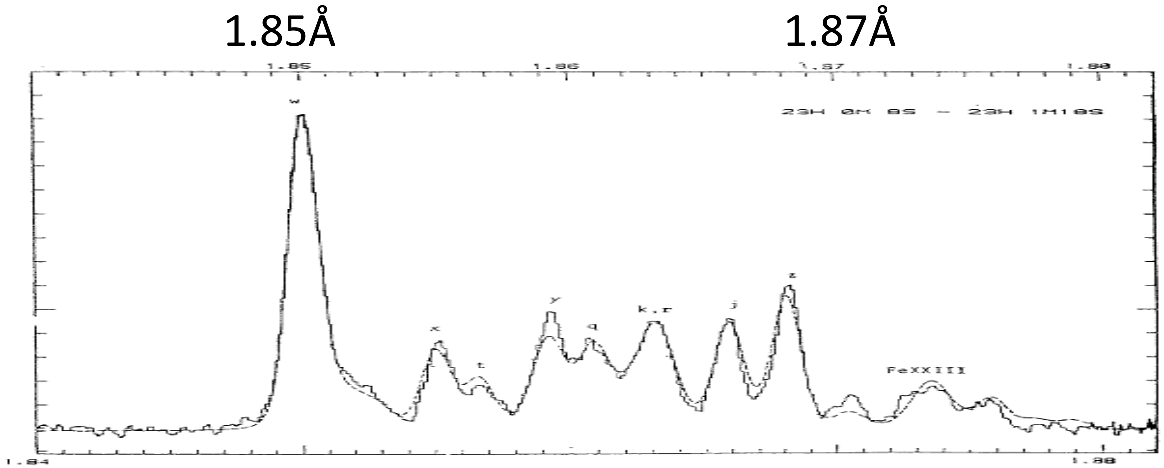
$$= \frac{1}{(1+\alpha)}F_1(T) \times F_2(S)$$

i.e. the ratio of the satellite line to the nearby parent or resonance line depends on temperature ***T*** (nearly $1/T$) and a factor $\boldsymbol{F_2(S)}$ (function of satellite S line's atomic physics and the ion: it is approximately proportional to Z^4, Z = atomic number).

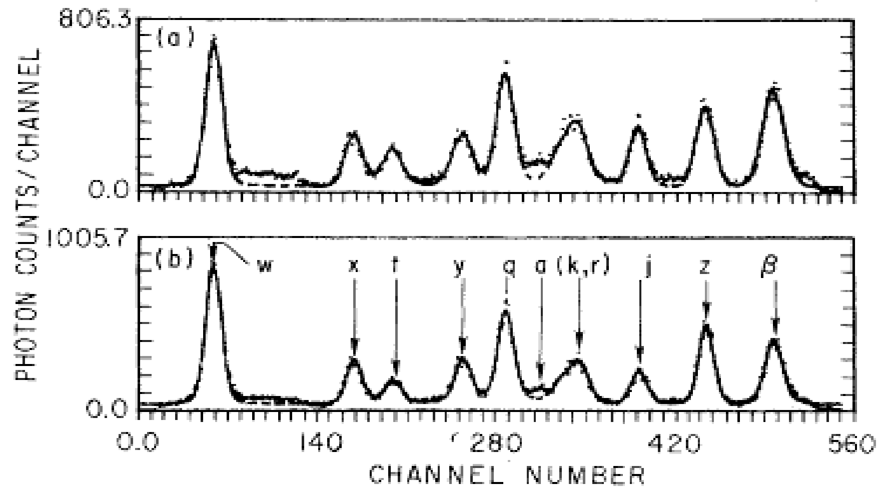
So satellites are (a) a **temperature diagnostic** and (b) **much more intense for heavier ions** e.g. Fe XXIV satellites near the He-like ion Fe XXV resonance lines seen in the X-ray spectra of hot (around 20 MK) **solar flare plasmas and fusion plasmas.**

Fe XXV + Fe XXIV satellite line spectra

High-resolution X-ray spectra from a solar flare & a fusion machine (PLT).

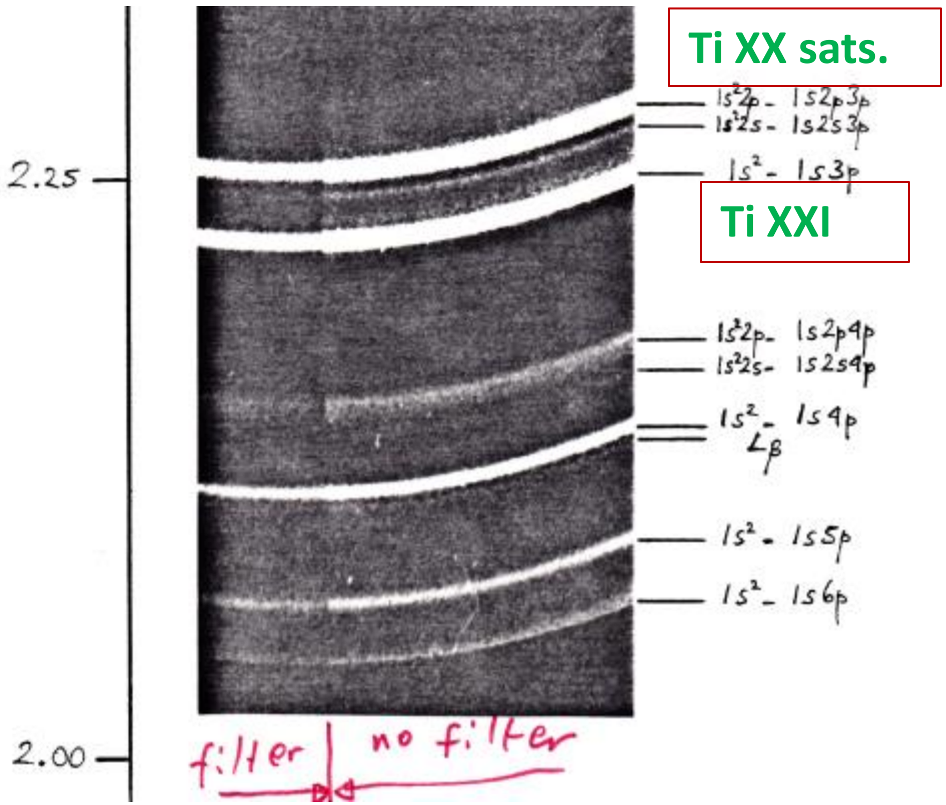


Tanaka (1985): Solar flare spectrum seen with Hinotori



Bitter et al. (1979): Tokamak (PLT) spectrum

Higher-order satellites



Wavelength scale (Å)

Photo credit: NRL and U. Feldman

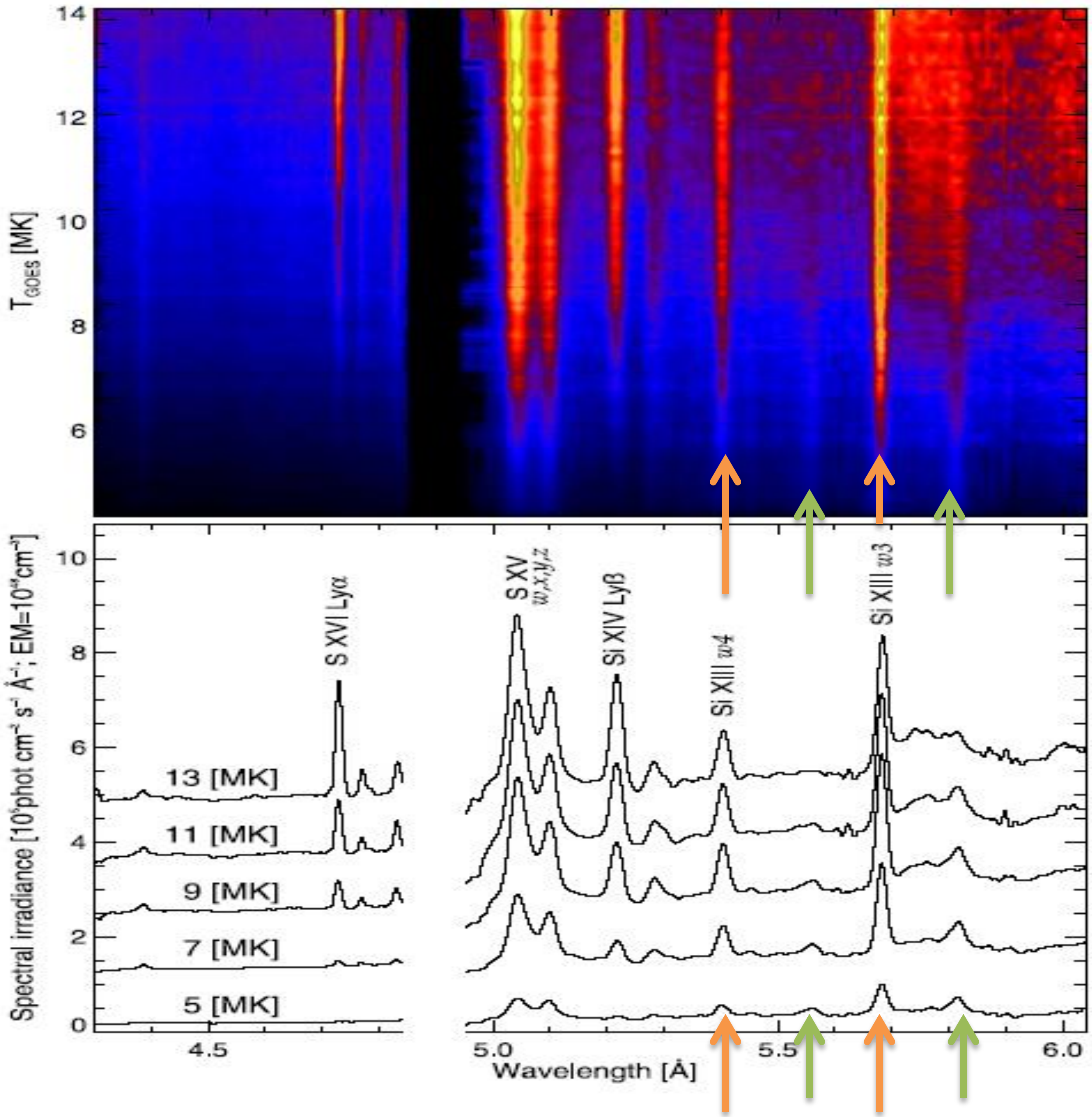
Not so much attention has been paid to satellites like

$1s^2\ 2p - 1s\ 2p\ 3p$

Like the $1s^2\ 2p - 1s2p^2$ satellites discussed by Alan, they are temperature-sensitive for hot plasmas. Unlike the $1s^2\ 2p - 1s2p^2$ satellites they form groups that are distinct from the parent (He-like ion) line (e.g. $1s^2 - 1s3p$ or w3) so are more easily resolved.

This is a spectrum from a NRL lab device, showing Ti XXI lines recorded photographically.

RESIK solar flare spectra: Si XIII + satellites



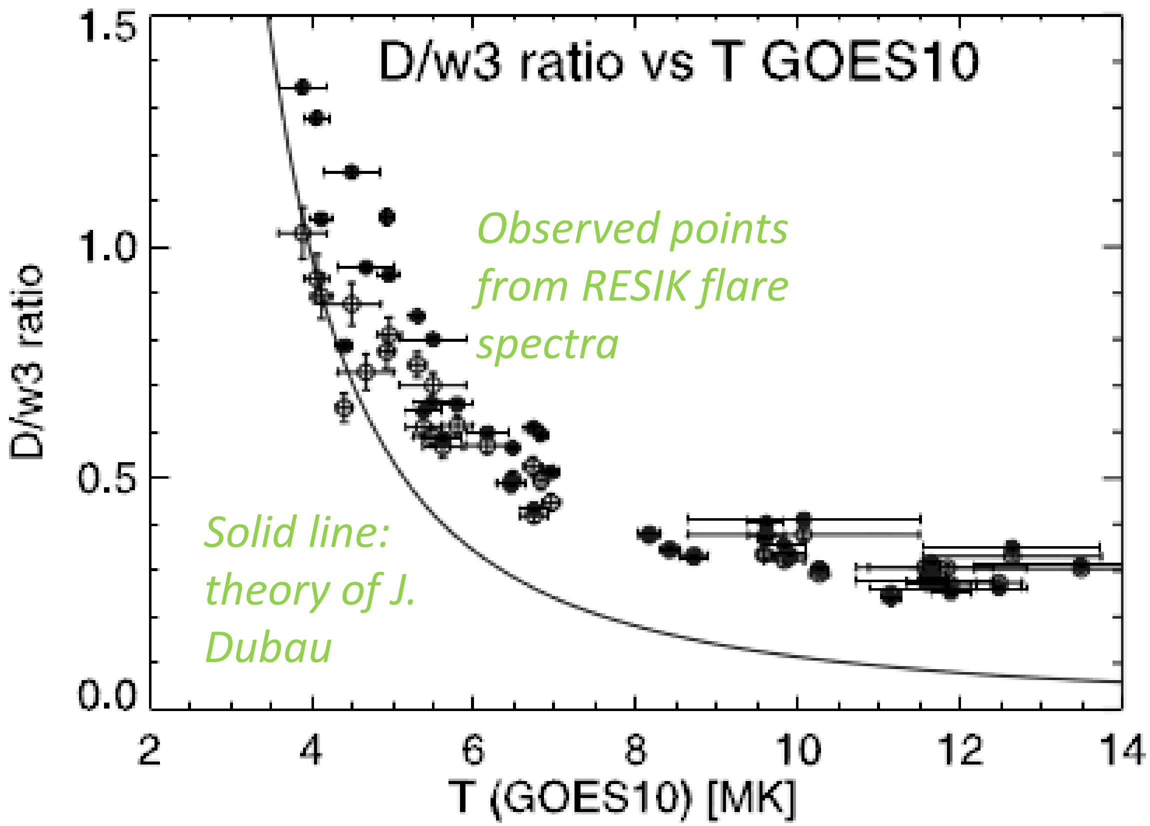
RESIK solar flare spectra stacked in ascending order of temperature (from GOES).

Orange arrows mark Si XIII w3 and w4 lines.

Green arrows mark nearby satellite line groups.

RESIK spectra courtesy of Janusz Sylwester et al.

Satellites (D) to Si XIII 1s^2 – 1s3p line in RESIK spectra



The D satellite feature/Si XIII w3 line ratio depends inversely on *T*, nearly as 1/*T*.

Temperature sensitivity of satellites

For the much hotter Fe XXV w3 ($1s^2$ – 1s3p) and the associated Fe XXIV satellites (e.g. $1s^2$ 2p – 1s 2p 3p), the $1/T$ trend should be very clear and enable temperature of the hottest parts of solar flare and fusion plasmas to be determined.

However, we have no high-resolution spectra during flares! (There are broad-band resolution flare spectra from several instruments but the satellites are not resolved.)

A clear need for either crystal spectrometers or microcalorimeters in this interesting spectral region.

Alan’s contributions

The original theory of satellite line formation was discussed in Alan’s 1972 paper and has been applied to numerous lab. and solar spectra.

Vast numbers of calculations of satellite intensities have been made by many research groups based on his theory.

At a recent count, there were well over 500 citations to Gabriel (1972), a tribute to Alan’s work.

Let’s not forget too the contributions made by Françoise and Jacques to this work. Their seminal papers with Alan and others in the 1970s and 1980s allowed interpretation of the X-ray spectra from SMM, Hinotori, Yohkoh, P78 and laboratory devices.