Adv. Space Res. Vol. 9, No. 12, pp. (12)97–(12)101, 1989
Printed in Great Britain.

0273–1177/89 $0.00 + .50

ELECTRON-CAPTURE SPECTROSCOPY FOR IDENTIFICATION OF SOURCE IONIZATION STATES AND ACCELERATION PROCESSES OF SCR

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ABSTRACT

It is illustrated how the radiation from electron-capture following the interaction of energetic ions, during their acceleration, with ions and atoms of the local matter is a very useful tool for diagnostics of cosmic and laboratory particle processes.

INTRODUCTION

Our knowledge of Plasma Physics from the laboratory to the space and astrophysical scales has been substantially supported by the development of a complex of experimental methods for diagnosing the properties of plasmas by direct or indirect proving and observational techniques, designated as Plasma Diagnostics /1,2/. In the case of indirect methods we have: 1st, Diagnostics based on the interaction of electromagnetic radiation with the plasma, using the own plasma radiation, or the trasmission of waves through the plasma, and 2nd, Diagnostics based on the interaction of corpuscular radiation with Plasmas and their E.M. fields. For reconigtion and identification of the searched information, it is needed of an information source for calibration, reason why Plasma Diagnostics is strongly based on the various kinds of spectroscopical methods.

We propose here a method based on the electron capture by accelerated ions of the free and bounded electrons in the plasma. It is attempted to show that the emitted radiation has very peculiar behavior as the interacting particles increase their energy, and is highly dependent on the acceleration process, and on the properties of the projectile ions and the parameters of the medium. This assorted behavior of emissions leads us to propose that a kind of spectroscopical Diagnostics might be developed to characterize energetic particle sources and associated phenomena. For the task of of illustration we develop here an example related with the generation of Solar Cosmic Rays (SCR).

THEORY

To elucidate whether the ions keep their local thermal charge state or not during their acceleration, the conditions for the establishment of charge transfer have been investigated in /3/, where a serie of criteria were developed for several acceleration mechanisms and for various ionization degrees of matter in the acceleration region. These criteria are based on the condition that a charge transfer process is established when the corresponding mean free path is shorter than the characteristic length of the acceleration step, provided that the later one be shorter than the mean free path for Coulomb inelastic collisions; i.e. a kind of competition between the charge transfer cross-section and the acceleration efficiency such that the flight time within the acceleration volume be enough long for the amount of traversed matter be higher than the mean free path of the charge changing process. So the criteria are translated into inequalities of the kind $\alpha < f(v,v_c,\sigma,N)$ where α is the acceleration efficiency, v the ion velocity, v_c the velocity where both the electron capture and loss cross sections are equated, N the medium density and $\sigma = \sigma(T,v)$ is the charge transfer cross-section, which according to /3/ is a function of the medium temperature. With the consideration that the acceleration rate must overcome the energy loss rate, the later criteria are finaly reduced to $1<(\alpha/\alpha_c)\cdot G(\sigma,v,v_c,\eta,T)$ where $\alpha_c = \alpha_c(v,\eta,N,T)$ is the critical value of the acceleration efficiency above which $(dE/dt)_a > (dE/dt)_L$ which depends on the kind of acceleration mechanism (η); as we will describe below; the density dependence of f an α_c cancels each other such that G is not sensible to N. For the specific case of electron-capture it is shown in /3/ that at $T \leq 2.5\times10^4$ °K where matter is predominantly in atomic state, electron capture is systematically established during ion acceleration. However at $T > 2.5\times10^4$ °K where matter is predominantly in ionized state, there is an abrupt fall in the cross-section because the drastic change in $v_r = v + v_t$, when v_t changes from the atomic to the electron thermal velocity, and $\sigma \sim v_r^{-2}$. However, since v_c increases faster with T than the corresponding decrease of σ with T, electron-capture is established at $T > 10^6$ °K due to the presence of heavy targets, since σ scales proportionally to the target atomic number Z_t. So electron capture in the domain $3x10^4 < T < 3x10^6$ °K takes place only with ultra-heavy ions, during an acceleration process. Since, any eventual confrontation of theory with observations requires an accurate temporal structure of the predicted emissions, here we consider the time-dependent energy spectrum of the projectil ions, by solving a Fokker-Planck type equation with no "Source term", which implies that the injection spectrum q(E,t)=0. This assumption corresponds to a scenario where particles are accelerated from thermal matter, the usually called as "first acceleration stage". In such situation the general solution is according to /4/ of the form

$$N(E,t,Z)=1.41x10^6 No.\ A(E'')\ (E''-mc^2)^{0.5} \exp[-(E''-mc^2)/kT-t/\tau]/A(E)T^{1.5} \quad (ions/eV.cm^3) \quad (1)$$

where τ is the energy independent mean confinement time of ions within the acceleration process, k is the Boltzman Constant, $N_o(Z)$ is the thermal density of ions to be accelerated, m is the mass of the accelerated ions, E" is the initial energy of ions in the thermal distribution, such that $1.5kT \leqslant E'' \leqslant E$, which appears from $t= \int_{E''}^{E} dE'/A(E')$ and A(E) are the acceleration rates: for Fermi acceleration $A(E)=dE/dt = \alpha\beta E$; for Betatron acceleration $A(E)= \alpha \cdot \beta^2 \cdot E$ and $A(E)= \alpha\beta$ for acceleration by fluctuating electric fields (E.F.), where β is the ion velocity in terms of the light speed; A(E") are the acceleration rates evaluated in E". The acceleration rates in the non-relativistic energy range, where electron capture takes place, may be expressed as $A(E)= \alpha\varepsilon^{\eta}$ with $\eta=1$ for Betatron acceleration and $\eta=0.5$ for Fermi and E.F. acceleration. To determine bounds in the value of α we make use of the electron capture criteria, such that $\alpha_c<\alpha<\alpha_c \cdot G(\sigma,v_c,\eta, T)$, and then we approximate by the assumption $\alpha \gtrsim \alpha_c \cdot (1+G)/2$, in such a way that we produce $\alpha =\alpha(E)$, whereas τ is kept as a free-parameter between $(10^{-2} -10)$s. Though G is not sensible to the medium density, it becomes strongly sensible on N, because its dependece on α_c (v,η,N,T).

The evaluation method of photo-emissions was described in /3/ and may be sumarized as follows: for a given acceleration mechanism, projectil ion, target ion or atom and source temperature, it is tested with the already mentioned criteria if electron pick-up is established, after it is determined at which orbital level there is capacity for accepting electrons, so that for that specific level we start to compare orbital radius with electron capture radius. Once n is determined the photon energy $h\nu=(1/2)\ mv^2 + X_n$ is evaluated from $h\nu = E(r_c)-E(r_n) = q^*e^2 / r_n-q^*e^2 / r_c$, and photon fluxes at 1 A.U., for a given acceleration volume V are

$$F(h\nu,t) = N(E,t,Z).N(Z_t)v.\sigma.\ h\nu.V/4\pi(1A.U.)^2 \qquad (photons/cm^2 \cdot s) \quad (2)$$

RESULTS AND DISCUSSION

Figure 1 shows the time profile of the emission produced by the interaction iron ions which are interacting at $T=10^7$ °K with thermal iron ions. It can be seen that E.F. acceleration produces more intense fluxes and in different energy bands than with Fermi acceleration. Moreover, the former fluxes last longer to disapear into the background than those from Fermi acceleration (∿ 20ms). These differences may be used to identify the acceleration mechanism. Since the emission energy band depends on the properties of the projectil and the medium, it is possible to identify the projectil, the target, temperature and volume of the source. Figure 2 shows that emission from ionized medium is in the form of narrow energy bands in the X-ray domain, which are very peculiar of the projectil ion and of the medium temperature. Figure 3 shows that the emission from atomic matter is a continum; for a same temperature, it can be seen that differences in the emission appear in the high energy domain (far UV and X-rays) produced by high energy ions which become to be highly stripped, and thus, differences in q* are more notables. This allows vs to infer about the charge state of ions, at least when electron capture stops. Figure 4 shows the characteristic time profiles of two infrared lines (49.7μm and,125.2μm) chosen from the continum. It can be seen that the time scale and intensity is very peculiar of each ion, even at the same wavelength; the acceleration process, the kind of projectil and targets, and parameters of the source can be deduced from this information. Figure 5 shows a transversal cut of the emission surface (F,hν,t) corresponding to the maximum emission fluxes: the emission from two different ion projectiles are quantitatively and qualitatively different in the UV domain. This jumps in the continum may help to identification of projectil ions.

CONCLUSIONS

The developed method permits to make a diagnosis about the source parameters, acceleration processes and properties of the accelerated ions: The flux intensity, their drift in

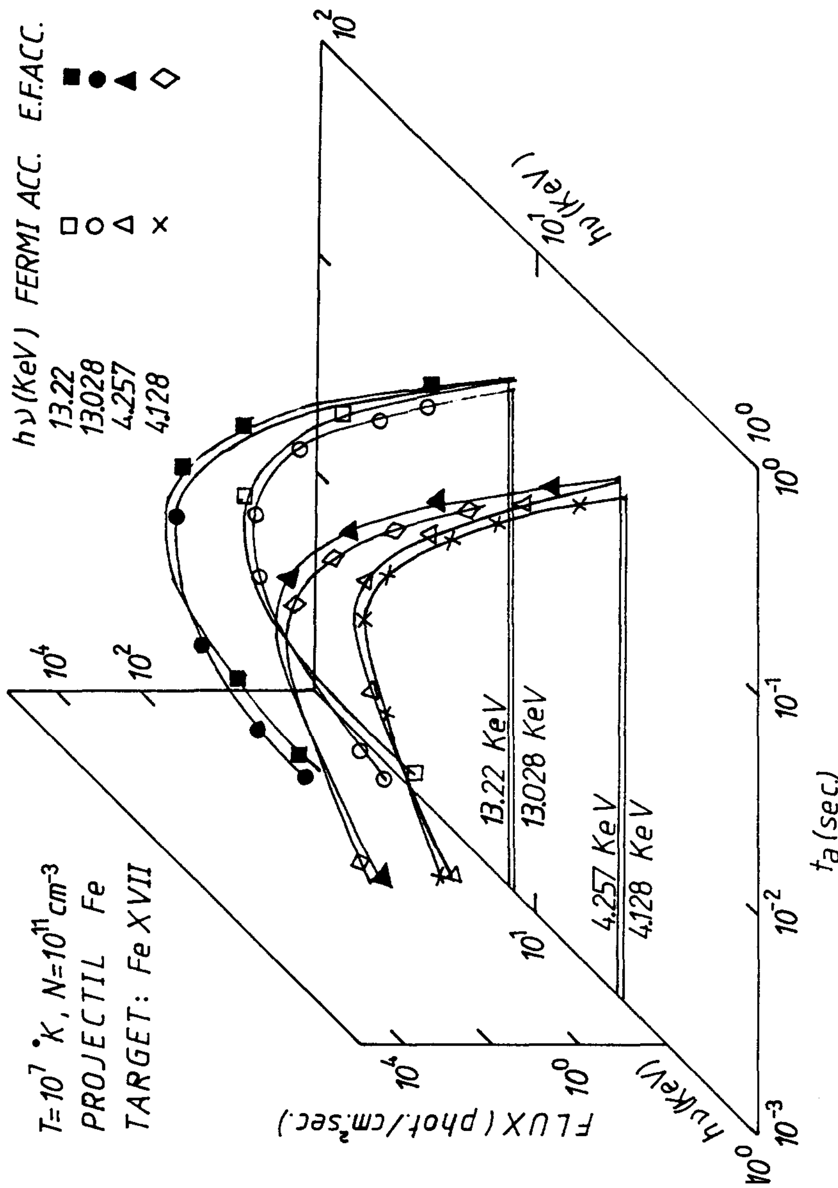

FIG.1 BEHAVIOR OF LINE EMISSIONS FOR TWO DIFFERENT ACC. PROCESSES

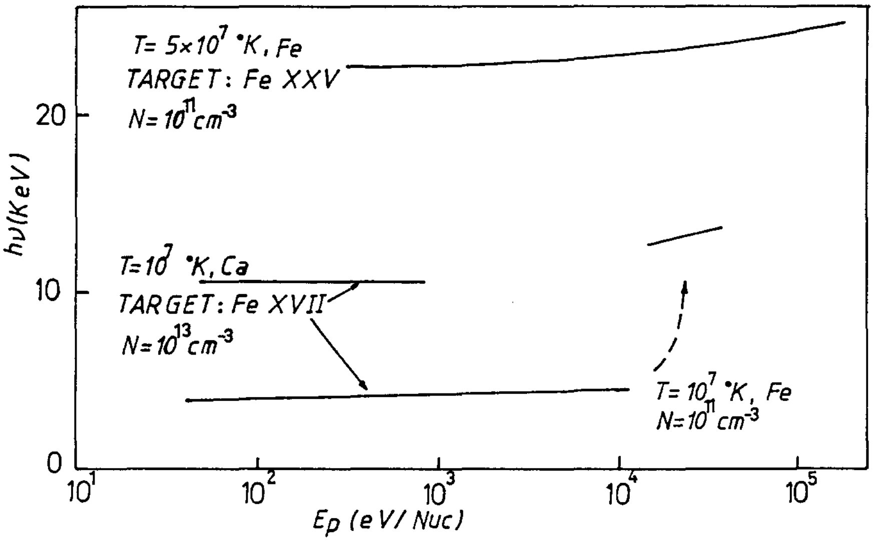

FIG.2 ELECTRON CAPTURE EMISSION DRIFT VS PROJECTIL ENERGY

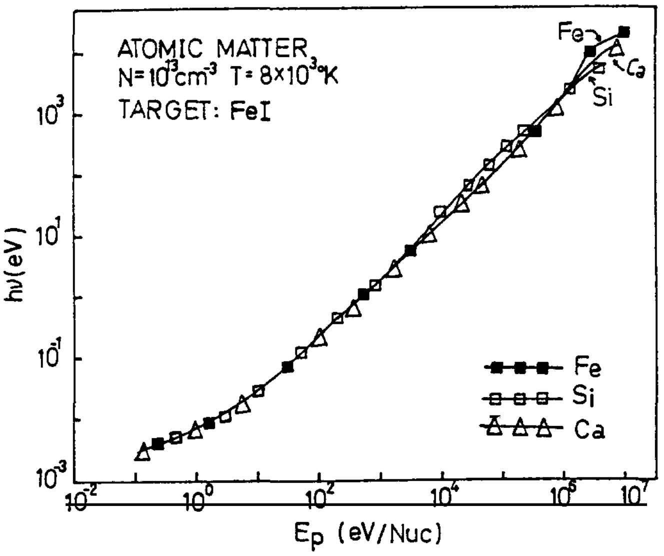

FIG. 3 ELECTRON-CAPTURE EMISSION DRIFT VS PROJECTIL ENERGY

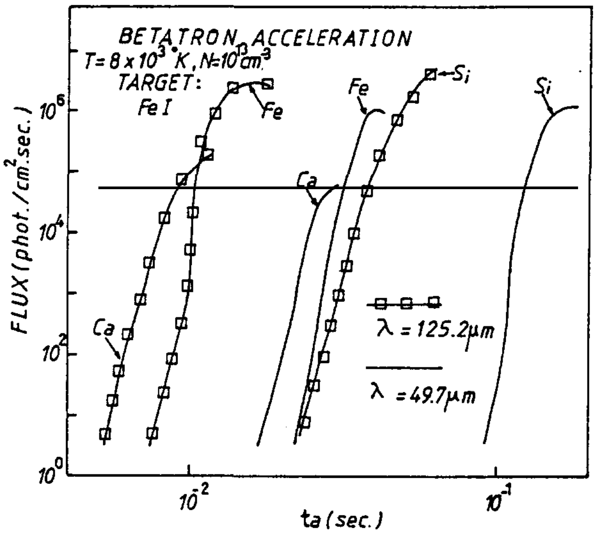

FIG. 4 TIME PROFILE (INFRARED)

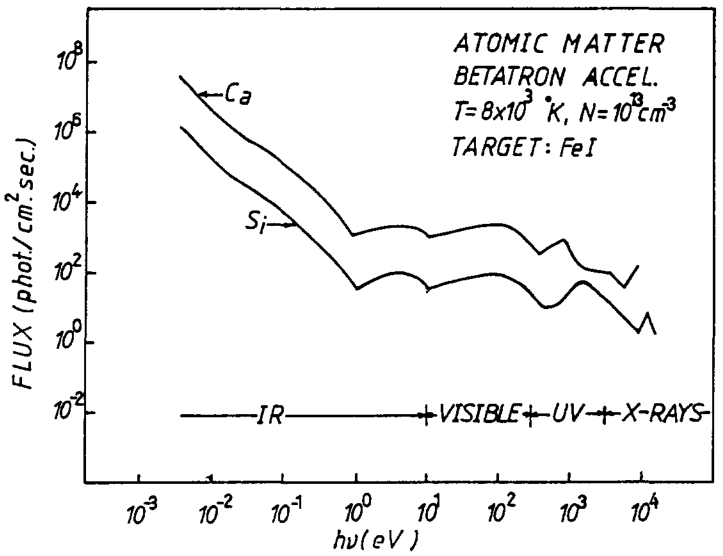

FIG. 5 ENERGY SPECTRA AT PEAK EMISSION TIMES

energy and time profile give information about the density, temperature and volume of the acceleration region, the kind of acceleration process involved and acceleration time scales during electron-capture emissions. So, it is possible to know the energy of ions as a function of time during acceleration. If this is known, the evolution of q* of the accelerated ions can be determined. The employement of this diagnostic method requires as first step, the delimitation in the observational fluxes of some characteristics that seems to be peculiar only for electron capture emissions: (1) a drift of energy in the continum of $\sim 10^{7}$ eV/s, (2) widths of time profiles in X-ray of $\sim 10^{-3}$ s for very well defined narrow bands, (3) time profiles widths of $10^{-2} - 10^{-3}$ s for specific wavelengths of the continum, (4) peculiar jumps in high energy fluxes of the continum. We claim that if most of these properties may be simultaneously identified, there are solid basis to develop an electron pick-up spectroscopy.

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