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ELECTRON CYCLOTRON RESONANCE (E.C.R.) MULTIPLY CHARGED ION SOURCES

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ABSTRACT.

High charge state ions can be produced by electron bombardment inside targets when the target electron density  $n$  ( $\text{cm}^{-3}$ ) multiplied by the ion transit time through the target  $\tau$  (sec) is:  $n\tau > 5 \cdot 10^9 \text{cm}^{-3}\text{sec}$ . The relative velocity between electrons and ions determines the balance between stripping and capture i.e. the final ion charge state. (In a stripper foil fast ions interact with slow electrons involving typically  $n = 10^{24} \text{cm}^{-3}$ ,  $\tau = 10^{-14} \text{sec}$ ). In the E.C.R. source a cold ion plasma created in a first stage diffuses slowly through a second stage containing a hot E.C.R. plasma with  $n > 3 \cdot 10^{11} \text{cm}^{-3}$  and  $\tau > 10^{-2} \text{sec}$ . Continuous beams of several  $\mu\text{A}$  of  $\text{C}^{3+}$ ,  $\text{N}^{4+}$ ,  $\text{Ne}^{9+}$ ,  $\text{Ar}^{11+}$  are extracted from the second stage with normalized emittances of  $\sim 0.5\pi \text{mm rad}$ . The absence of cathodes and plasma arcs makes the source very robust, reliable and well-fitted for cyclotron injection. A super conducting source is under development.

GENERALITIES.

High charge state ion beams for positive ion accelerators can be produced by electron bombardment of atoms and ions in a plasma or by stripping of fast ions in a foil or gas. In electron bombardment sources, the ions move slowly at around thermal velocities, and the electrons move at much higher velocities. Since it is the relative velocity of the electrons and ions which is important, the high charge states can also be produced by passing accelerated ions through a stripping foil or gas cell where the electrons have very low velocities.

If one assumes a plasma in Corona equilibrium (i.e. long particle life time, step by step ionizations, and only radiative recombinations) one can postulate that with 100 to 1000 eV electron temperatures, the ions reach the same average charge state  $\langle Z \rangle$ , as ions of respectively 1 to 1/2 MeV/nucleon would reach after passing a gas stripper. In Corona plasma,  $\langle Z \rangle$  only depends on electron temperature  $T_e$  (Fig. 1) Unfortunately, in laboratory plasmas the particle lifetime is generally limited by insufficient confinement time  $\tau$  and Corona is not achieved. Under this condition,  $\langle Z \rangle$  not only depends on  $T_e$  (or more accurately on the relative velocity  $w$  of electrons and ions) but also on the electron density  $n_e$  ( $\text{cm}^{-3}$ ) and on the exposure time of the ions to the electron bombardment  $\tau$  (sec.) (Fig. 2), (Fig. 3) give some computed results of this so called non stationary Corona equilibrium. In a previous papers we summarized the  $Z$  ion production in four typical cases as shown in Table 1.

$n_e \tau$ $\text{cm}^{-3} \text{sec.}$	$T_e$	$w$ $\text{cm/s}$	Ion charge state $Z$
a) whatever	<10 eV	<2.10 <sup>8</sup>	No multiply charged ions
b) $\sim 10^8$	<100eV	<6.10 <sup>8</sup>	low Z multiply charged ions.
c) $\sim 10^{10}$	<5 keV	<4.10 <sup>9</sup>	totally stripped light ions.
d) $\sim 10^{12}$	<20keV	<10 <sup>10</sup>	totally stripped heavy ions

Example b) represents typically the PIG ions sources and the Duoplasmatrons. It also holds for a single stage E.C.R. plasmas (MAFIOS sources Fig. 5).

Example c) holds for foil strippers, EBIS sources, and present day multiple stage E.C.R. plasmas (Supermafios sources) /1/, /2/, /3/, /4/. Let us also recall that foil strippers, gas strippers and E.C.R. plasma strippers are based on the same collision mechanism involving similar relative velocities  $w$  of electrons and ions and similar  $n\tau$  values. The outstanding differences between foil strippers or gas strippers and E.C.R. strippers can be summarized as follows: In the first case the main effort must be devoted to the MeV/amu ion production (preaccelerator) in the second case to the hot electron plasma production. (plasma confinement structure). Due to the high electron density of solid matter ( $n_e \sim 10^{24}$ ) if one wants to achieve  $n\tau \sim 10^{10} \text{cm}^{-3}\text{sec}$  in a stripper foil one needs a transit time of only  $\tau = \frac{L}{w} > 10^{-14} \text{sec}$ .

where  $L$  is the foil thickness ( $\sim 10^{-5} \text{cm}$ ) and  $w$  the ion transit velocity ( $> 10^9 \text{cm/s}$ ). A similar image is valid for an E.C.R. plasma stripper but  $n_e$  being of the order of  $10^{12} \text{cm}^{-3}$  one needs very long ion transit times ( $\tau$  must be  $\sim 10^{-2} \text{sec}$ ). The plasma has to be as thick possible ( $\sim 100 \text{cm}$ ). Even so, the ion transit velocity ought to be  $\sim 10^4 \text{cm/sec}$ , which is smaller than the thermal velocity of ice cold ions. Only some collision dominated ion diffusion can provide a  $10^4 \text{cm/sec}$  transit velocity. Fortunately such transit velocities exist the ambipolar plasma diffusion processes where colliding electrons and ions are held together for a while in a magnetic structure. The transit time then equals the ambipolar diffusion time given by the well known formulae

$$\tau_{DIF} = L^2 / D_{amb}$$

where  $L$  is the plasma length in the magnetic structure and  $D_{amb}$  the ambipolar diffusion coefficient along the plasma. On the other hand,  $D_{amb}$  is proportionnal to  $\langle v_i \rangle^2 / \nu_{ii}$ , where  $\langle v_i \rangle$  is the average thermal ion velocity and  $\nu_{ii}$  is the Spitzer ion/ion collision frequency which varies with the plasma density  $n$  and  $Z^4$ . One then deduces that the ion transit time  $\tau$  increases proportionnally with  $Z^3 n$ . Therefore  $n\tau_{DIF}$  increases automatically when the average ion charge  $Z$  inside the plasma increases. /5/. The plasma stripping efficiency can then improve through a feed-back type mechanism.

Finally E.C.R. strippers are "undestroyable" and the construction of an equivalent E.C.R. stripper line is much easier and cheaper than the foil stripper line (Fig. 4).

II - STRATEGY OF E.C.R. PLASMA STRIPPERS.

Four important parameters are involved in plasma stripping. The plasma density  $n$ , the electron temperature  $T_e$ , the ion exposure time to the electron bombardment  $\tau$ , and the residual gas pressure of atom density  $N_0$ .

a) Plasma density and electron heating problems.

In the first E.C.R. plasmas /6/, /7/, we proved very readily that the gyroresonance of the electrons is a powerful and reliable mechanism for plasma generation allowing adjustable electron heating.

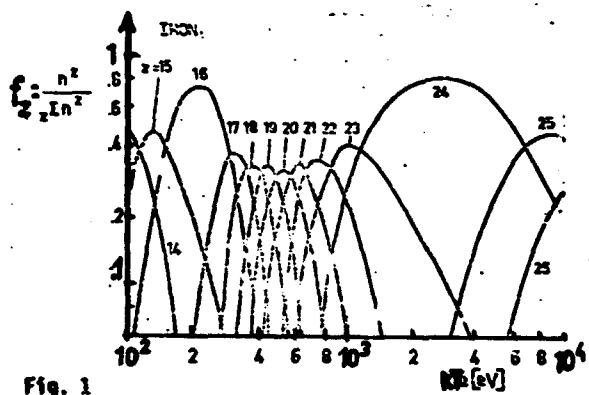


Fig. 1 - Fractional abundances of Iron Ion charge states, versus electron temperature in Corona equilibrium.

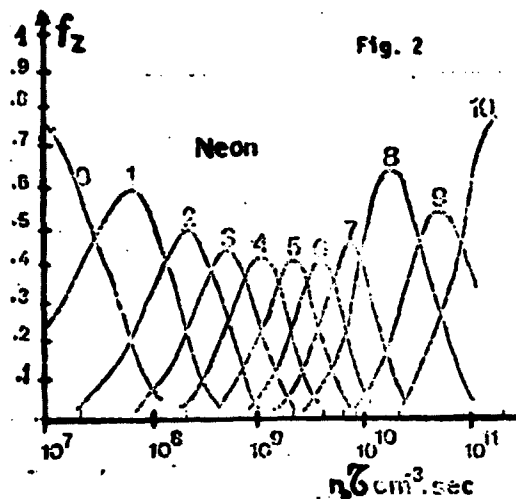


Fig. 2 - Fractional abundances of Neon Ions in non-stationary Corona equilibrium, versus  $n_e \tau$  with electron temperature  $T_e = 12 \text{ keV}$ .

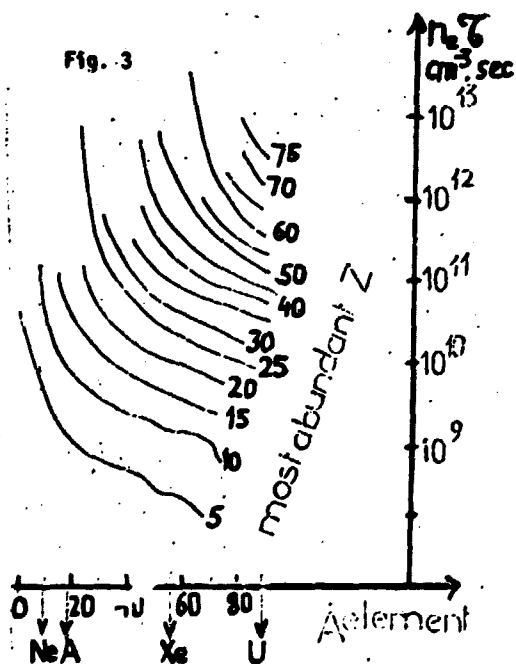


Fig. 3 - Knowing the theoretical ionization cross sections for step by step stripping one can evaluate the most abundant ion charge state  $Z$  in a non stationary Corona equilibrium versus  $n_e \tau$ , for all elements. In the present graph  $T_e = 10 \text{ keV}$  (Ref. /9/). One can see that  $n_e \tau > 10^{10}$  is necessary for complete stripping of Neon and  $n_e \tau \leq 10^{12}$  for complete stripping of Xenon.

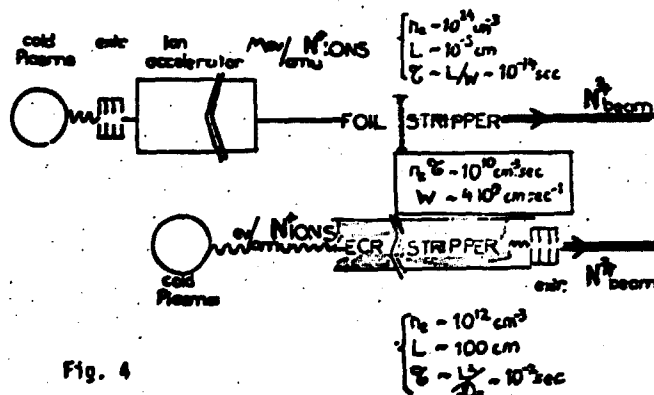


Fig. 4 - Comparative stripper lines for obtention of completely stripped Nitrogen  $N^{7+}$  ion beams.

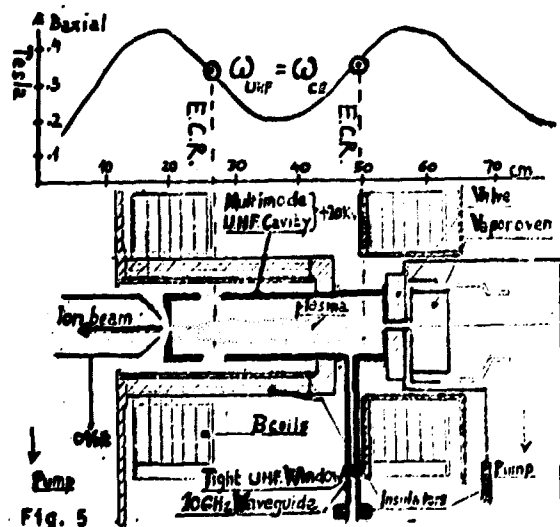


Fig. 5 - A typical Mafios ion source for vapor ion production. Vapor pressure inside the multimode UHF cavity is  $\leq 10^{-4}$  Torr.

These results were obtained (without cathodes and arcs) simply by feeding microwave power into a magnetic structure where the resonance condition  $\omega_{UH} = \omega$  is fulfilled somewhere. The power transfer efficiency from the microwaves to the plasma electrons is generally excellent (50% - 100%) and the power coupling techniques simple and well known (cavities, waveguides or antennas).

The plasma density  $n$  is however limited by the cutoff density for wave penetration, ( $n_{UH}^{cutoff} = \omega_{UH}^2 / \omega^2 n^2 c^2$ ) and commercially available CW microwave generators in the kW range do not deliver frequencies higher than 36 GHz. Typically for 10 GHz and 1 kW the plasma density can reach  $\leq 10^{12} \text{ cm}^{-3}$  and with present day microwave sources  $n_e$  will not exceed  $10^{13} \text{ cm}^{-3}$ .

The electron heating is a quite easier problem. As a matter of fact, if the resonant acceleration is not too much hindered by collisional damping, keV electrons are rapidly produced and multiply charged ions are created. Without any precautions concerning the magnetic confinement structure at values of  $\sim 10^8 \text{ cm}^{-3} \text{ sec.}$  were obtained ( $\tau \leq 10^{-4} \text{ sec.}$ ) in the MAFIOS sources Fig. 5.

#### b) Ion and electron life time problems.

Let us assume that electron heating is no longer a problem in E.C.R. plasmas and keV electrons are always available. If one now wants totally stripped light ions (such as  $O^{8+}$ ,  $N^{7+}$ , etc..) (Fig. 3) shows that  $n_e \tau$  must be of the order of  $10^{10} \text{ cm}^{-3} \text{ sec.}$  As  $n_e$  is limited by the present day commercially available microwave frequencies, one sees the need of long ion exposure times ( $\tau > 10^{-3} \text{ sec.}$ ) i.e. ion confinement. Now another difficulty arises. /8/.

Let us consider the flux of electron energy that is required to satisfy the stripped ion production. Writing  $v$  for R.M.S. electron velocity, this flux equals

$$\phi_e = n_e v k T_e \tau_{ion} / 2$$

For totally stripped light ions we need

$$n_e \tau \sim 10^{10}, T_e \sim 5 \text{ keV}, (v \sim 4 \cdot 10^9 \text{ cm/s.})$$

If then  $\tau$  equals 1 sec.,  $\phi_e$  becomes  $\sim 16 \text{ kJ/cm}^2$ .

However we know that in the best plasma devices, the ion life time hardly reaches  $10^{-2} \text{ sec.}$  Under these conditions, the experimentalist has to create inside his stripper box an impressive electron power flux of  $\sim 1,6 \text{ MW/cm}^2$ .

We also must keep in mind that every decrease in ion lifetime must be compensated by an increase of  $n_e k T_e$  (i.e. by an increase of the microwave power input into the plasma). For a quasi continuous E.C.R. plasma regime one sees immediately the strong motivation for not only achieving long ion exposure times but also confinement for the electrons so that they dissipate their kinetic energy after more than one pass by an ion. With a microwave power of a few kW the only reasonable way for achieving a continuous flux of  $1,6 \text{ MW/cm}^2$  consists in creating a small electron flow of let us say  $1,6 \text{ kW/cm}^2$  ( $T_e \sim 5 \text{ keV}, 0,32 \text{ amp/cm}^2$ ) and forcing this flow to pass a thousand times through the plasma (and the same  $1 \text{ cm}^2/\text{plane}$ ), before getting lost. In other words to trap the hot electron and the ions in an efficient plasma confinement system, such as, for example, a high performance mirror device.

For these purposes we built a magnetic bottle with a  $B_{min}$  structure obtained by superimposing a solenoidal and hexapolar magnetic field. Such a structure suppresses generally plasma turbulence and improves both electron and ion lifetimes.

#### c) The neutral pressure problem and the extracted beam current.

In a foil stripper, with MeV/nucleon ions, the charge exchange problems can be neglected. In the E.C.R. plasma stripper, where the ions are cold, charge exchange can only be avoided if the presence of neutral atoms is minimized inside the plasma. Therefore background pressures of  $p \sim 10^{-6} \text{ Torr}$  are desired if one wants to obtain high Z charged ions. However it is difficult to reach  $10^{12} \text{ cm}^{-3}$  plasma density by ionizing a neutral gas of only  $10^8 \text{ cm}^{-3}$  background density. For this reason we divided the source into two stages. In a first stage where the pressure is high, we create a dense cold F.C.R. plasma which diffuses towards a second stage where the pressure is as low as possible. In this second stage hot electrons are generated and confined in the minimum B structure and the cold ions are stripped gradually during their transit. The pumping facilities must be adjusted to the plasma losses in the stripper box because the ions and electrons hitting the walls are retransformed into neutral gas and represent a heavy gas load.

Therefore it would be interesting to minimize the plasma volume i.e. the plasma diameter. However we are rapidly limited in this direction by the ion current one wants to extract.

As the ions in the E.C.R. stripper are thermalized by the collisions, one needs as in ordinary sources an ion extraction system in order to obtain transportable ion beams. If we want to extract from the plasma, let us suppose  $5 \cdot 10^{13}$  ions/s in the most abundant charge state  $\langle Z \rangle$  (which represents about 10% of the total), we have to extract a total  $\sim 5 \cdot 10^{14}$  ions/s.  $S$  being the area of the hole of the extractor, we have to satisfy the relation

$$\frac{n^+ v^+ S}{4} \approx 5 \cdot 10^{14} \approx \frac{n^- v^- S}{4 \langle Z \rangle}$$

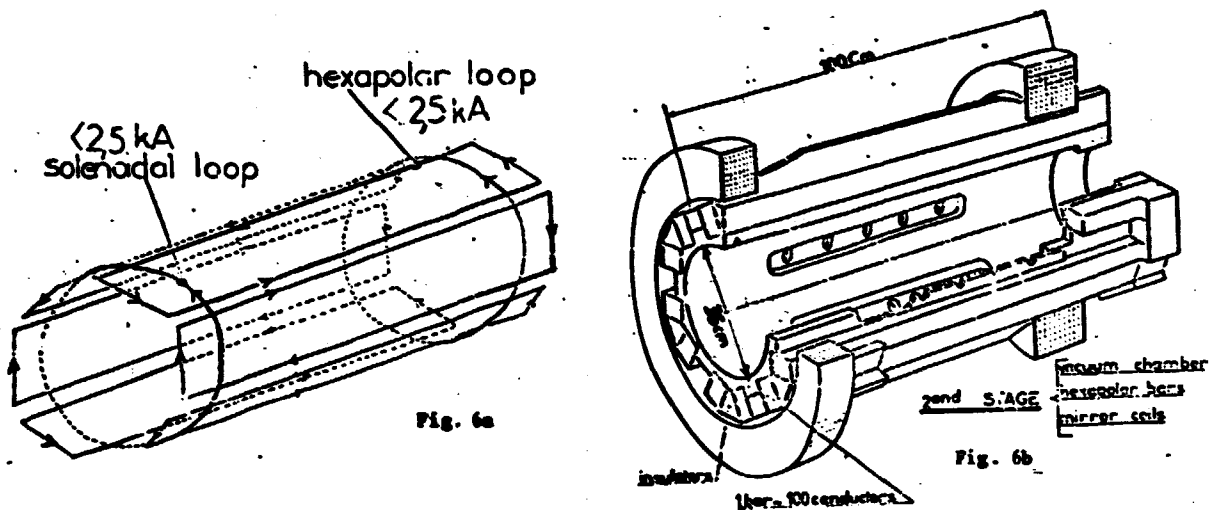
Knowing that the thermal speed of cold ions  $v^+$  is about  $10^5 \text{ cm/s.}$ ,  $S$  would be  $\sim 1 \text{ cm}^2$ . It results that the area of the plasma within the source must be greater than  $1 \text{ cm}^2$  in order to cover the extraction hole. If we accept that 5% of the plasma ions are extracted (this is rather a large number for a continuous ion source) then the lost ions represent a gas flow of  $3 \cdot 10^{-4} \text{ Torr l/sec.}$  As we want  $10^{-6} \text{ Torr}$  pressures, 30 000 l/s. of pumping would be necessary in the second stage. Obviously one has to find a compromise. However to maximize pumping speeds in our E.C.R. stripper source (SUPERMAFIOS) the second stage is imposing. The diameter of the vacuum chamber is 35 cm.

This has to be paid in terms of electrical consumption in the  $B_{min}$  structure ( $\sim 3 \text{ MW}$ ) to establish the necessary magnetic volume (Fig. 6a and Fig. 6b).

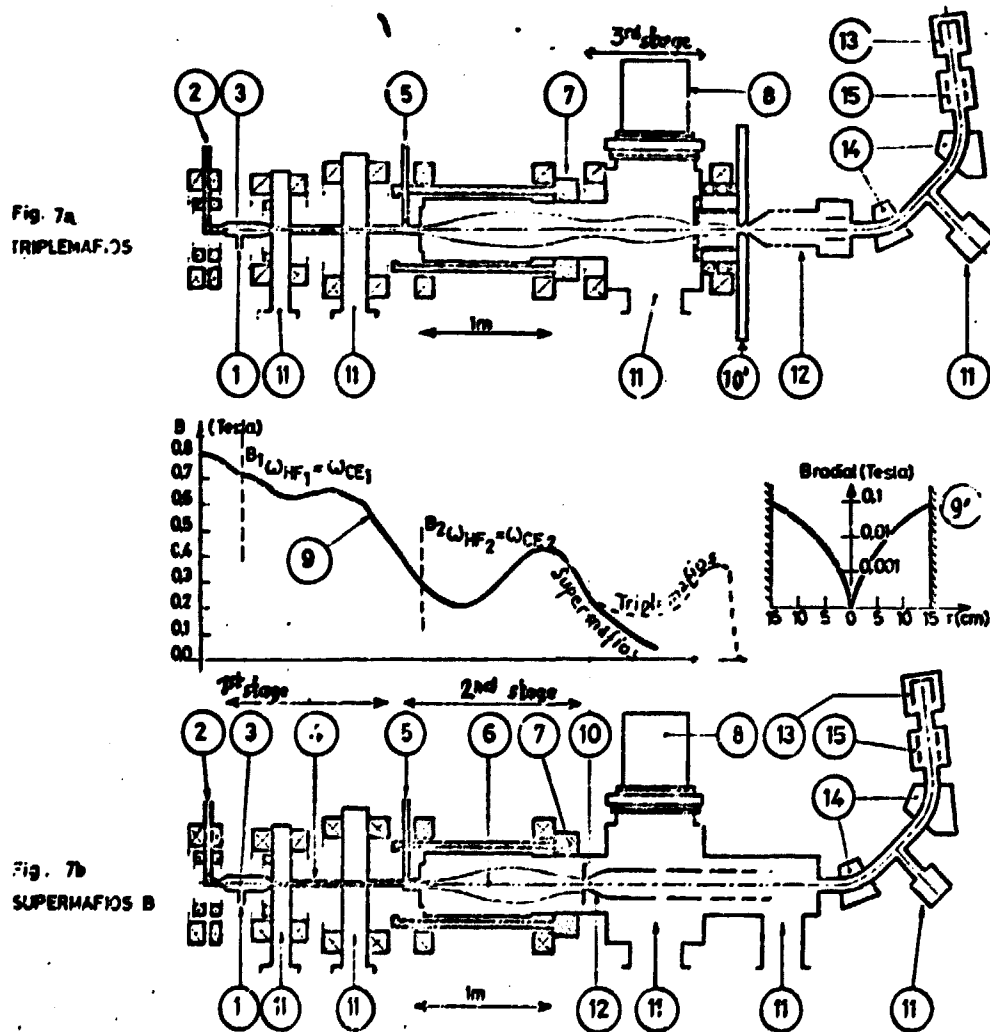
### III - DESCRIPTION OF THE SOURCE SUPERMAFIOS B.

This is the name of our last version plasma stripper. (Fig. 7b).

The source is characterized by its big geometrical dimensions, offering adequate conductance for pumping in the stripper stage (In total, more than 10 000 l/s. by diffusion pumps to which is added 30 000 l/s by Titanium pump). The device works in 2 stages. The first stage is a plasma injector (gas pressure  $10^{-2} - 10^{-4} \text{ Torr}$ ) where we create by a first electron cyclotron resonance



**Fig. 6 - The stripper stage with its "minimum B field" disposal :**  
 6 a) electrical currents  
 6 b) mechanical disposal



**Fig. 7 a et b - Multistage ECR strippers.**

- 1 - gas injection - 2 - Waveguide for the 1<sup>st</sup> stage (16 GHz) - 3 - 1<sup>st</sup> stage ECR plasma injector ( $10^{-2}$  Torr) -
- 4 - Cold plasma diffusing towards the stripper stage - 5 - Waveguide for the second stage (8 GHz) - 6 - Second stage containing the hot ( $\sim 10$  keV) electron plasma ( $p \sim 10^{-3}$  Torr) - 7 - Hexapole - 8 - Titanium pump -
- 9 - Axial magnetic field profile - 9' - Radial magnetic field in 2<sup>nd</sup> stage - 10 - Extraction hole (B. 2500 Gauss) -
- 10' - Extraction hole in ferromagnetic shield and expansion cup (B. 0 Gauss) - 11 - Pumpings - 12 - Extractor -
- 13 - Faraday cup - 14 - Deflecting magnets - 15 - Movable emittance meter.

(useful power  $H.F. < 1$  kW,  $\omega_{HF1} = \omega_{CE1} = 2\pi \cdot 16 \cdot 10^9$  Hz,  $B_1 = 0,6$  Tesla) a cold plasma which can already contain ions of low charged states. Thus, we do not have any filaments, nor electrodes in this injector.

After a differential pumping (gas pressure  $\sim 10^{-7}$  Torr) a second stage is constituted by the magnetic structure with  $B_{min}$  towards which diffuses the injected plasma and whose electrons undergo a second cyclotronic resonance (useful power  $P_{HF2}$  goes from 1 to 5 kW,  $\omega_{HF2} = \omega_{CE2} = 2\pi \cdot 8 \cdot 10^9$  Hz,  $B_2 = 0,3$  Tesla). This resonance heats the electrons up to an energy of 1 to 10 keV. By ambipolar diffusion, the ions and the electrons are retained some time in the magnetic structure. Here the ionizing collisions of the electrons with ions contribute to increase the mean charge state  $\langle Z \rangle$  of the ions.

The extraction hole is located at the end of the magnetic bottle in a 2500 Gauss B field ( $\phi = 1,4$  cm). In our previous versions (TRIPLEMAFIOS, SUPERMAFIOS "A") Fig. 7a, 15/1/6 the extractor was located behind a plasma expansion volume inside a low B field. However our experiments showed that the beam quality is not affected by a strong magnetic field, whereas more current can be extracted because the plasma density is not diluted.

#### IV - EXPERIMENTAL RESULTS OF SUPERMAFIOS "B".

Some typical results concerning currents, normalized emittance  $\epsilon_n$  (mm.m rad) and ion charge are given in the Table 2. They indicate the number of particles/sec. delivered continuously by the source with 12 kV extraction and transported to the emittance meter and Faraday cup (Fig. 7b) (distance  $\sim 300$  cm). Fig. 8 shows an Argon Ion spectrum and ion current versus extraction

CARBON	NITROGEN	OXYGEN	ARGON	XENON
$C_{3+} 10^{14}$	$N_{5+} 5 \cdot 10^{13}$ $\epsilon_n \sim 1$	$O_{4+} 10^{14}$	$A_{8+} 3 \cdot 10^{13}$ $\epsilon_n \sim 0,8$	$Xe_{10+} 4 \cdot 10^{12}$
$C_{3+} 2 \cdot 10^{13}$	$N_{6+} 8 \cdot 10^{12}$ $\epsilon_n \sim 0,5$	$O_{6+} 3 \cdot 10^{13}$	$A_{10+} 8 \cdot 10^{12}$ $\epsilon_n \sim 0,4$	$Xe_{18+} 5 \cdot 10^{11}$
	$N_{7+} 5 \cdot 10^{12}$ $\epsilon_n \sim 0,5$	$O_{7+} 10^{13}$	$A_{12+} 10^{12}$	$Xe_{26+} 4 \cdot 10^{10}$

Fig. 9) shows some emittance shapes and values and Fig. 10) a typical Nitrogen ion spectrum containing also high charge state impurity ions. Fig. 11) compares Nitrogen ion currents versus Z with the behaviour of the theoretical cross section ratio for step by step ionization

$$\left(\frac{\sigma_{s+}}{\sigma_s}\right) T_e = 5 \text{ keV}$$

Fig. 12) Compares yields of Nitrogen ion currents obtained with different sources.

The multistage E.C.R. stripper source was under operation from 1974 to 1977. It allowed us to study different problems such as the best magnetic structure, the wave plasma interactions and the wall problems. The performances were gradually improved. However not one single break down or erosion failure occurred inside the source for  $\sim 2000$  working hours! The only troubles we encountered were trivial and due to breakdown of external supplies. Let us notice that the extraction system was not optimized and better ion currents will

be obtained with a specially adapted system. In addition, we could easily improve the present performances by minimizing charge exchange through still better vacuum pumping. In situ cryopumping would in this case be necessary. But we arrived to the crucial question: Is it worthwhile to install cryogenics without Superconducting magnetic coils?

The electric power consumption of 3 MW is excessive for many utilizes. Superconducting coils would therefore be an attractive solution.

#### V - THE SUPERCONDUCTING PROJECTS. : CRYOMAFIOS.

Different versions are proposed. In the simplest project, only the second stage is superconducting which reduced the electrical power consumption to  $\sim 150$  kW. In another version, the device is all Superconducting but the vacuum chamber remains at room temperature and the vacuum pumps are located outside like in Fig. 13. Eventually in a high performance project, parts of the walls are at 20°K providing an important additional cryopumping /10/(10 liters of liquid He/hour). Let us emphasize that the Superconducting E.C.R. strippers would allow us, to increase the magnetic field and subsequently to utilize higher frequencies in the resonance zones. In this case the hot electron density,  $n_e$  which is proportional to  $\omega_{HF}$ , could also be increased. Such a change would not only improve the factor  $n_e/N_0$  but also  $n_e \tau$  because the diffusion time is proportional to

$$\left(\frac{L}{\langle v \rangle}\right)^2 \frac{Z^4 n_e}{\tau^{3/2}} \text{ i.e. } \frac{L^2 Z^4 n_e}{\tau^{5/2}}$$

(presently in the second stage at 8 GHz the cut off density is  $8 \cdot 10^{11} \text{ cm}^{-3}$  whereas the routine working density is of the order of  $3 \cdot 10^{11} \text{ cm}^{-3}$ ). If the frequency of HF2 could be raised up to 16 or 36 GHz the electron density should achieve respectively  $1,2 \cdot 10^{12} \text{ cm}^{-3}$  and  $6 \cdot 10^{12} \text{ cm}^{-3}$ . Now let us suppose two eventualities:

##### a) Pessimistic extrapolation:

By increasing  $\omega_{HF}$  we only increase  $n_e$ , the diffusion time  $\tau$  remaining constant (extra losses due to some unforeseen turbulence). Fig. 14 then indicates what kind of Z ion charge can be reached in Cryomafios if

one utilizes commercially available microwave generators, and recalling that the superconducting coils are capable of furnishing the corresponding B field for E.C.R. Totally stripped ions up to Xenon are expected.

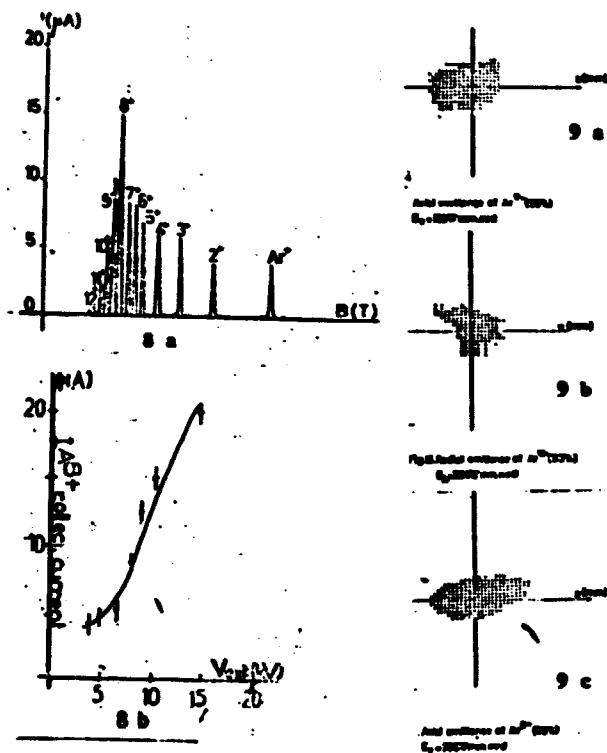
##### b) Theoretical extrapolation:

Not only  $n_e$  rises but also  $\tau$ , because  $\tau$  is proportional to  $Z_{eff}^2 n_e$ . By increasing the density up to  $n_2 = 20 n_e$ ,  $\tau_2 = 20 \left(\frac{2}{Z}\right)^3 \tau$  and  $n_2 \tau_2$  becomes such that all the ions up to Uranium will be completely stripped in Cryomafios.

At last, but not least, the Cryomafios source would be cheaper than the classical version (because in the present case the magnetic power supplies and coils are the most expensive part of the device) and as well, it would enable its settlement on a high voltage platform.

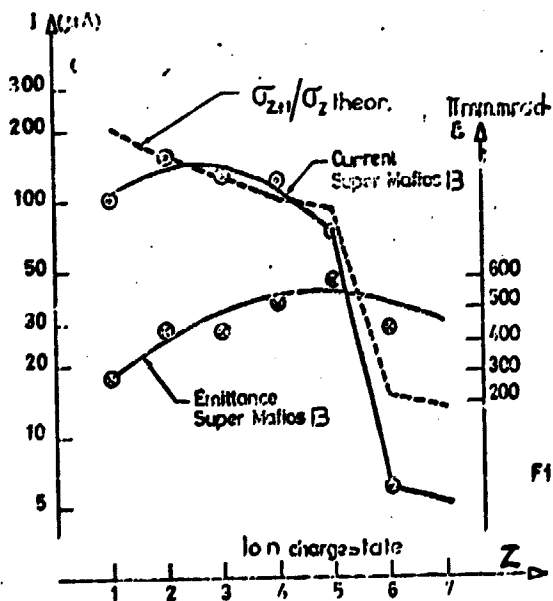
#### VI - THE PERMANENT MAGNET MULTISTAGE E.C.R. STRIPPER.

Knowing exactly the optimal magnetic configuration of Supermafios "B" we came to the conclusion that the second stage can be build with upto data permanent magnets provided that  $\omega_{HF}$  does not exceed 10 GHz. In other words, the present day performances are achievable in a Supermafios "B" version with the electrical power consumption minimized to  $< 200$  kW. A small two stage

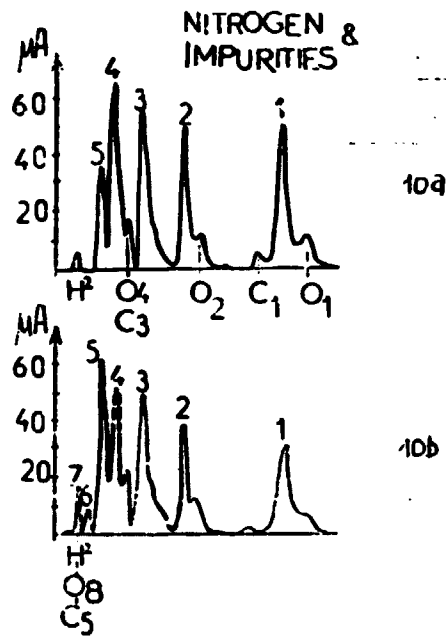


**Fig. 8a** - Argon Ion Spectrum collected on the Faraday cage.  
**8b** -  $A^{8+}$  current versus extraction voltage. Neutral pressure in the stripper stage  $2.10^{-7}$  Torr. Microwave power  $P_{UH1} = 0,15$  kW,  $P_{UH2} = 2$  kW

**Fig. 9** - Typical Argon beam emittances for  $A^{8+}$ ,  $A^{9+}$  and  $A^{10+}$  ions



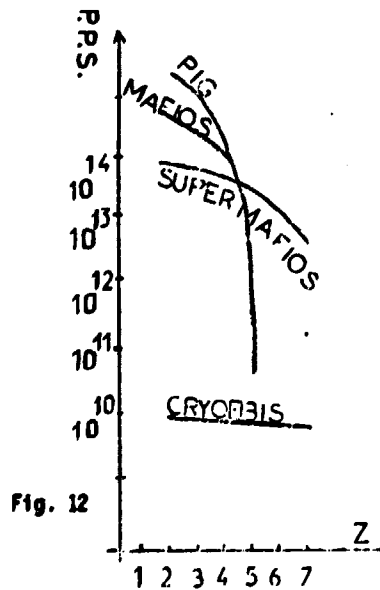
**Fig. 11** - Nitrogen beam currents and beam emittances versus ion charge state  $Z$  at 10 kV extraction. The dashed line indicates the theoretical ratio of step by step ionization for 5 keV electrons.



**Fig. 10** - Nitrogen charge state distribution.

10 a)  $P_{UH1} = 0,1$  kW,  $P_{UH2} = 1,1$  kW,  $p = 2.10^{-7}$  Torr  
 10 b)  $P_{UH1} = 0,1$  kW,  $P_{UH2} = 1,5$  kW,  $p = 2.10^{-7}$  Torr

By increasing the microwave power in the stripper stage,  $T_e$  increases and reaches the threshold. For complete stripping of light ions.  $N^{7+}$ ,  $O^{8+}$  and  $C^{5+}$  ions appear in the spectrum.



**Fig. 12** - Comparative nitrogen ion yields for different ion sources.

ion source is now under construction for tests. First results are expected in early 1979. (Fig. 15).

### VII - CONCLUSION.

The multistage E.C.R. stripper devices are today the only highly stripped ion sources enabling continuous or long duration pulsed regimes with stable and intense beams and adequate emittances. Therefore they look like the last tool for cyclotrons where the energy per nucleon could be rapidly increased by a factor 4 to 6 just by eliminating the obsolete PIC sources and utilizing E.C.R. strippers. But by nature they are external sources and have to be adapted and settled on a separated high voltage platform. For synchrotron injection, they can easily work with short pulses, and their working pressure in the range of  $\sim 10^{-8}$  Torr makes them well fitted with respect to gas back-diffusion coming from the accelerator. Let us also recall that an E.C.R. stripperline, is much cheaper than the usual foil or gas stripperline and that the E.C.R. stripper is not life-time limited.

E.C.R. strippers are not only fitted for accelerators, but also for fundamental research on heavy ions. They furnish quasi noiseless beams which become after selection excellent targets of stripped ions with densities of the order of  $< 10^{12} \text{ cm}^{-3}$ . These targets enable cross section measurements for ionization, recombination, excitation etc... in a range of ion charge states never studied before.

New microwave power generators (called gyrotrons) in the range up to 120 GHz will be commercially launched in the next five years. Combined with a superconducting stripper stage they will enable the production of completely stripped heavy ion beams for cyclotron injection.

### REFERENCES.

- /1/ - R. GELLER, XIII Intern. Conf. Phen. Ion Gases Berlin, G.D.R. September 1977, p. 103.
- /2/ - D. CLARK, Nucl. Sc., Vol. N.S 24, 3, (1977).
- /3/ - E.D. DOWETS, Nucl. Sc., Vol. N.S. 23, 2, (1976), p. 897.
- /4/ - J. ARIANER, C. GOLDSTEIN, Nucl. Sc., Vol. N.S.23, 2, (1976), p. 579.
- /5/ - M. BRIAND et al., G.S... Rep. p. 3, October 1977, Darmstadt p. 42 (1977).
- /6/ - R. GELLER, Nucl. Sc. Vol. N.S. 23, 2, (1976), p. 904.
- /7/ - S. BLIMAN et al., N.I.M. 148 (1978), p. 213.
- /8/ - T.S. STIX, Nucl. Sc., Vol. N.S. 19, 2, (1972), p. 150.
- /9/ - J.D. DAUCHERTY et al., Res. Rep. 333, Avco Everett Res. Lab. (1969).
- /10/ - G. CLAUDET, Note S.BT 433, C.E.N/Grenoble (1977).

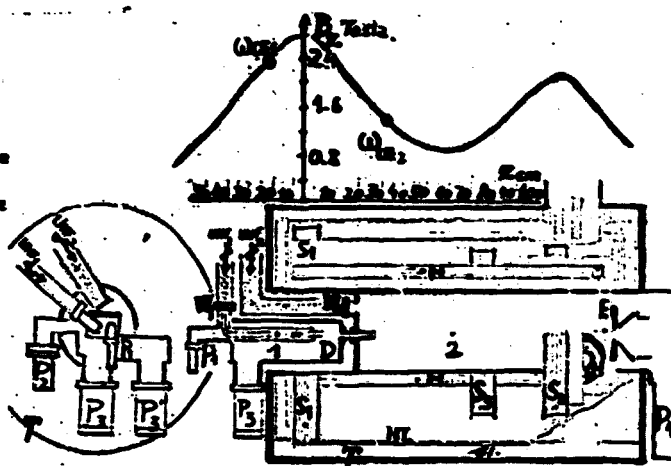


Fig. 13 - Cryomafios II

In this version the pumping is classical, but the magnetic field can reach 1,4 T in the stripper stage resonance. Then  $\omega_{CE1} = 55 \text{ GHz}$  and  $\omega_{CE2} = 36 \text{ GHz}$ .

- . 1 - 1<sup>st</sup> ECR stage
- . 2 - 2<sup>nd</sup> ECR stripper stage
- P. - Vacuum pumps
- D - differential pumping Box
- M. - microwave windows
- S1 - Super isolation
- S. - solenoids
- H - hexapole
- H.T - Liquid Helium Tank.
- T - Vacuum Tank
- E - extraction electrodes.

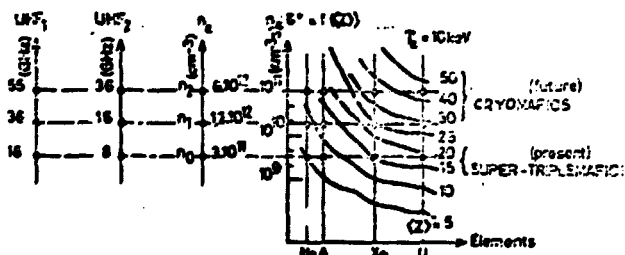


Fig. 14 - Cryomafios II possibilities :  
With Superconducting magnets (i.e. increasing B) one can utilize 36 GHz in the Stripper stage. A very pessimistic extrapolation shows that  $n_0 = 6 \cdot 10^{12} \text{ cm}^{-3}$  and  $n_{eT} = 10^{11} \text{ cm}^{-3}$  will be reached, and completely stripped Xenon ions produced. A more realistic extrapolation predicts completely stripped  $U^{92+}$  ions.

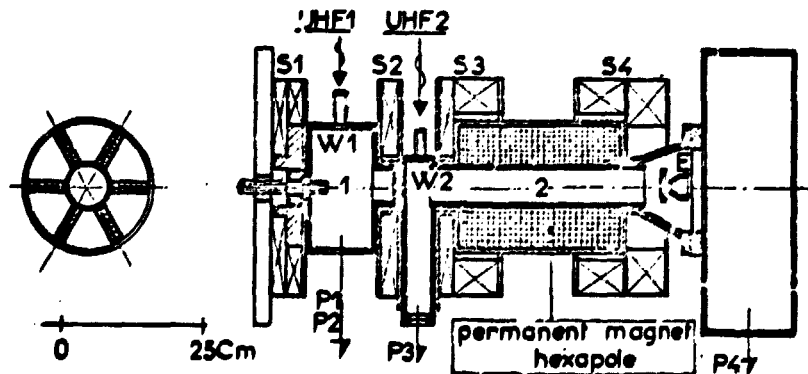


Fig. 15 - Micromafios I.

This ECR stripper is a miniaturized Supermafios with only 50 kW Electric power consumption.