Plasmas for
Astrophysics,
Nuclear
Decays
Observation and
Radiation for
Archaeometry

David Mascali for the PANDORA collaboration

LNS Users Meeting, Catania - December 11th, 2018

Magnetized Plasmas for interdisciplinary research at INFN-LNS

LNS plasma team topics

Fundamental plasma investigation

Wavelet-Analysis

RF probes

Advanced Sensors R&D

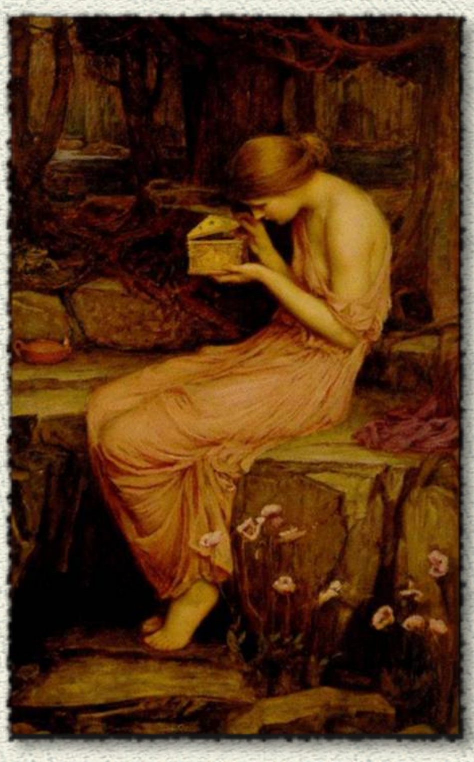
Ion Beams Production

High-Resolution X-ray Spectroscopy

Ultra Compact Proton Source & negative noble-gas ions injector

Optical Emission Spectroscopy

RF Polarimetry



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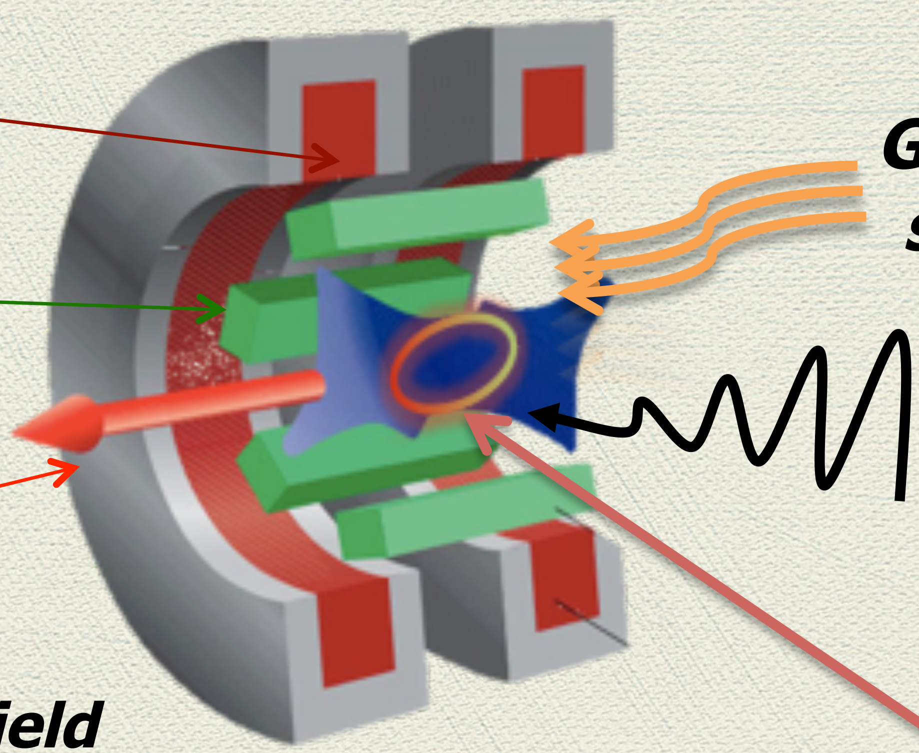
The B-min configuration

suitable for multiply charged ions production

***Solenoids** for*
Axial confinement

***Hexapole** for*
radial confinement

Extraction system

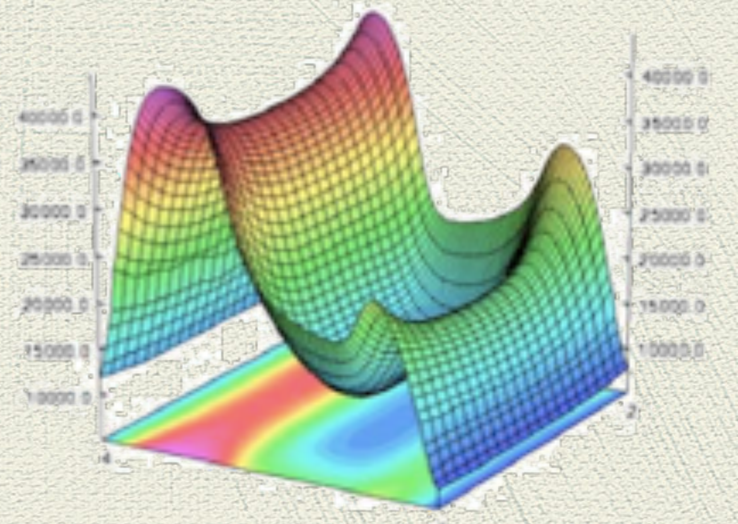


Gas injection system

Incident microwaves
*few **kW** at **tens GHz***

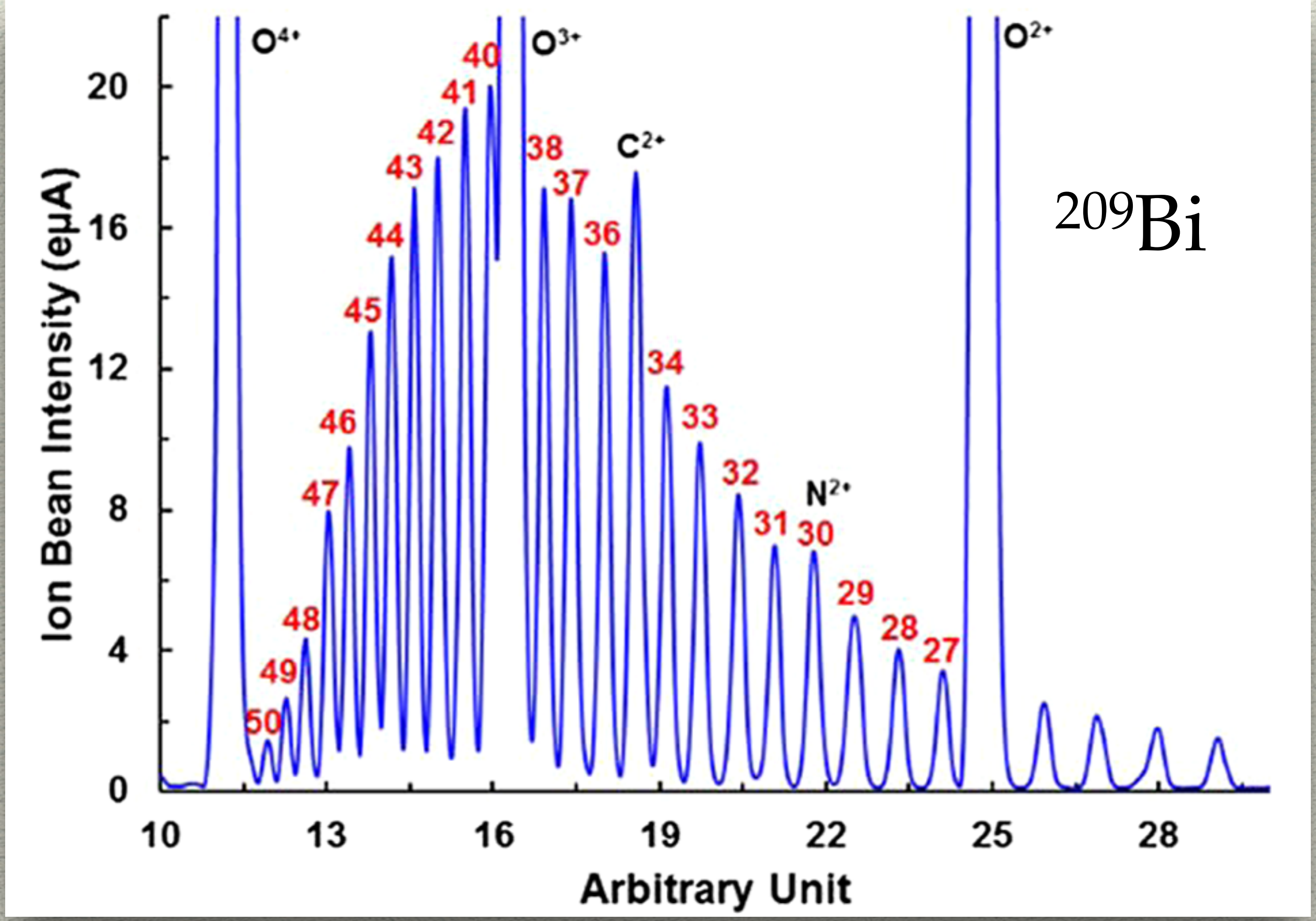
ECR Surface
$B_{ECR} = \omega_{RF} m_e / e$

"B_minimum" Magnetic Field
structure



el. dens. 10^{12}-10^{14} cm^{-3}
el. temperature 0.01-10 keV

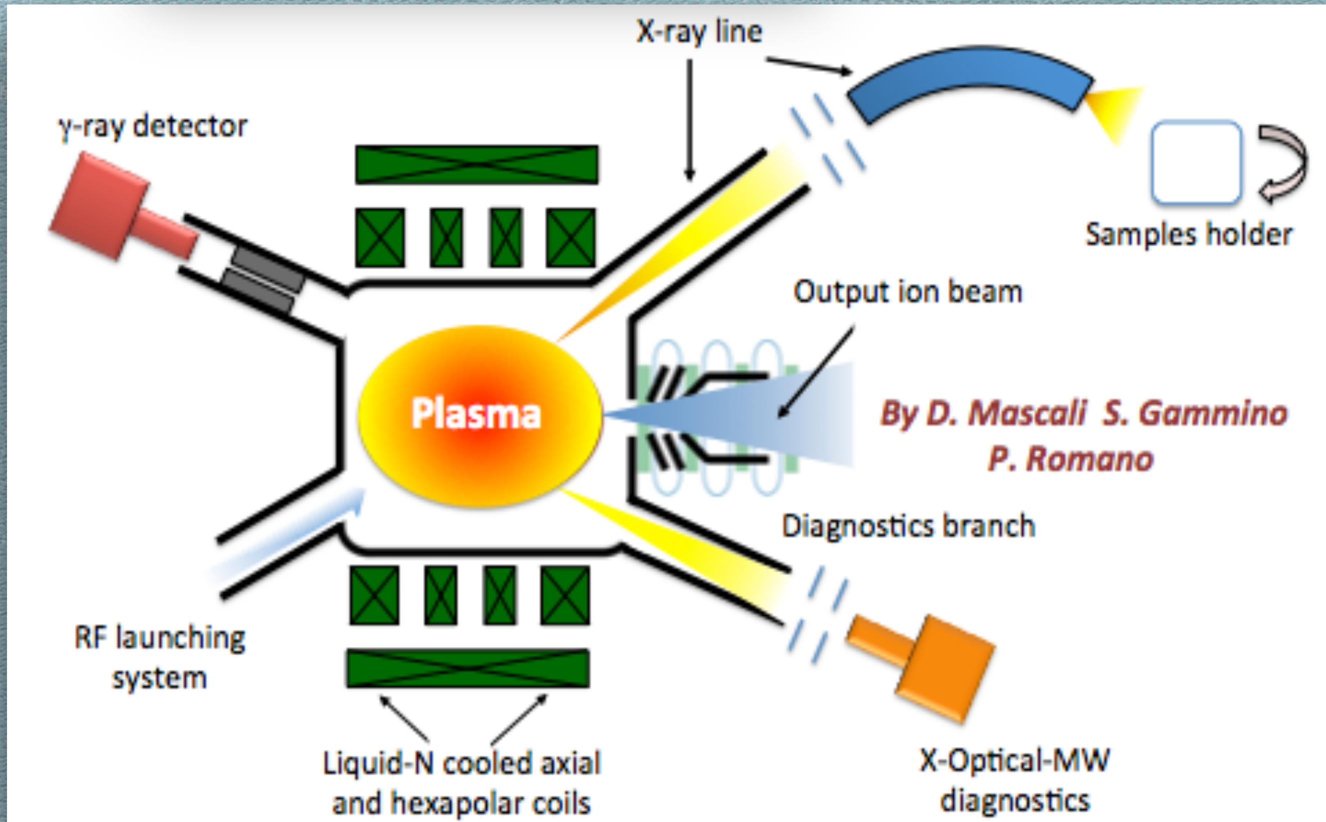
Confinement of highly charged ions in a magnetoplasma

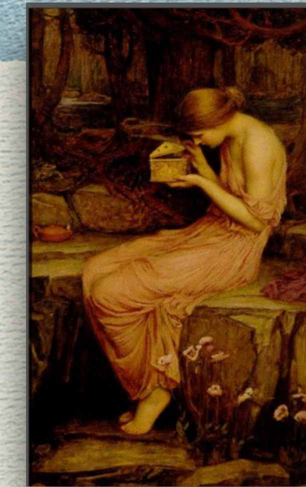


SECRAL source at IMP - Lanzhou, China

According to the plasma density, temperature and confinement time, a given charge state distribution can be mainteined in a dynamical equilibrium for hours or even days!!

1. Plasma can be obtained by (almost) any element, including rare isotopes
2. The Charge State Distribution can be modulated according to the plasma density and temperature
3. The decay-products can be tagged by γ-rays or by XRF on accumulation targets





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S-process

^{85}**Kr** [$T_{1/2}$ = 10.76 y, ***s-process***, γ@514 keV]

^{176}**Lu** [$T_{1/2}$ = 38 Gy, (***CosmoChronometers***) γ @ 202.88 & 307 keV]

^{187}**Re** [$T_{1/2}$ = 50 Gy, (***CosmoChronometers***), no γ —> ^{187}Os.]

^{87}**Rb** [$T_{1/2}$ = 48 Gy, (***CosmoChronometers***), no γ —> ^{87}Sr.]

^{7}**Be** [$T_{1/2}$ = 53 d, (***BBN, solar neutrino***) γ @477.6 keV.]

CosmoChronometers

Magnetoplasmas in laboratory

Opacities for MM physics

Let's trap beta-decaying radionuclides in magnetoplasma, thus studying if and how the lifetime is affected by the atomic charge state and by the "environment"

Experiments in S. R. and theory say β-decays lifetimes are modified by the atomic charge state

VOLUME 74, NUMBER 4 PHYSICAL REVIEW LETTERS 23 JANUARY 1995

Effects of the Hyperfine Interaction on Orbital Electron Capture

L. M. Folan and V. I. Tsifrinovich

Physics Department, Polytechnic University,
(Received 1

Low Z, hydrogenlike ions have sn
tings and low radiative relaxation rates
needed to deplete the upper hyperfine
ment. This probably can be achieved
exchange collision techniques [15].
system for this type of experiment is ^{7}
magnetic moment of ^{7}Be has not been measured, but it is expected to be about $-1.3\mu_N$ [16]. Approximately 10% of ^{7}Be nuclei decay to ^{7}Li*, with a decrease in spin of one unit, followed by emission of a single, experimentally detectable, γ ray. If $F = 2$ is, in fact, the lower hyperfine level of the ground state, then with $\Delta \gg kT$ the decay to ^{7}Li* would be forbidden and an ion cloud would emit no γ rays. This provides the exciting possibility of controlling and switching a nuclear decay using hyperfine transitions. Driving the population into the $F = 1$ state with a resonant electromagnetic π pulse will induce decay to ^{7}Li* followed by emission of γ rays.

PRL 99, 262501 (2007) PHYSICAL REVIEW LETTERS week ending 31 DECEMBER 2007

Measurement of the β^+ and Orbital Electron-Capture Decay Rates in Fully Ionized, Hydrogenlike, and Heliumlike ^{140}Pr Ions

Yu. A. Litvinov,[1,2] F. Bosch,[1] H. Geissel,[1,2] J. Kurcewicz,[3] Z. Patyk,[4] N. Winckler,[1,2] L. Batist,[5] K. Beckert,[1] D. Boutin,[2] C. Brandau,[1] L. Chen,[2] C. Dimopoulou,[1] B. Fabian,[2] T. Faestermann,[6] A. Fragner,[7] L. Grigorenko,[8] E. Haettner,[2] S. Hess,[1] P. Kienle,[6,7] R. Knöbel,[1,2] C. Kozhuharov,[1] S. A. Litvinov,[1,2] L. Maier,[6] M. Mazzocco,[1] F. Montes,[1,9] G. Münzenberg,[1,10] A. Musumarra,[11,12] C. Nociforo,[1] F. Nolden,[1] M. Pfützner,[3] W. R. Plaß,[2] A. Prochazka,[1] R. Reda,[7] R. Reuschl,[1] C. Scheidenberger,[1,2] M. Steck,[1] T. Stöhlker,[1] S. Torilov,[13] M. Trassinelli,[1] B. Sun,[1,14] H. Weick,[1] and M. Winkler[1]

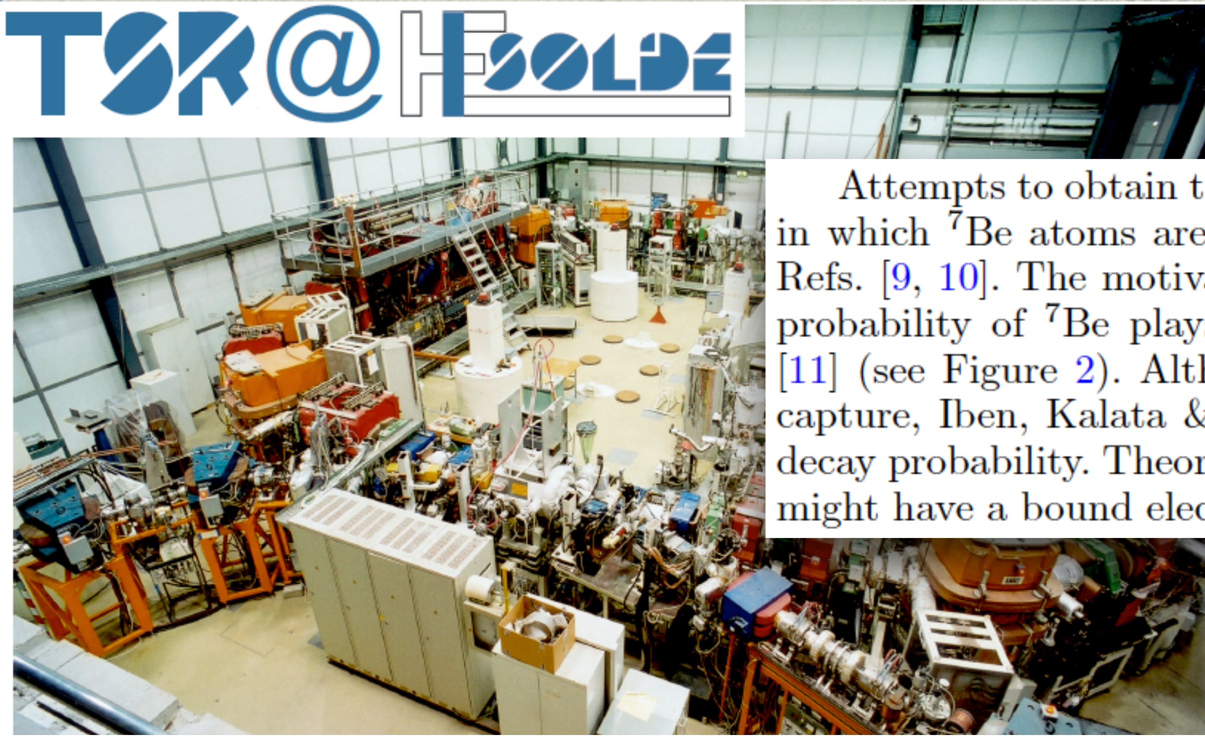
TABLE I. Measured β^+ and EC decay constants obtained for fully ionized, hydrogenlike, and heliumlike ^{140}Pr ions. The values are given in the rest frame of the ions.

Ion	λ_{β^+} (sec^{-1})	λ_{EC} (sec^{-1})
$^{140}Pr^{59+}$	0.001 58(8)	...
$^{140}Pr^{58+}$	0.001 61(10)	0.002 19(6)
$^{140}Pr^{57+}$	0.001 54(11)	0.001 47(7)

EC-lifetime variation already observed in Storage Rings

Competitive/Complementary approaches

TSR@ISOLDE



Half-lives of ^{7}Be in different atomic charge states

Attempts to obtain the "true" terrestrial half-life of ^{7}Be are done in numerous experiments worldwide in which ^{7}Be atoms are implanted in different chemical environments, see, e.g., recent experiments in Refs. [9, 10]. The motivation for studying this decay is its impact for Solar physics, where the survival probability of ^{7}Be plays a crucial role for the neutrino fluxes from the ^{7}Be EC- and ^{8}B β^+-decays [11] (see Figure 2). Although the main decay channel of ^{7}Be in the Sun's interior is the free electron capture, Iben, Kalata & Schwartz [12] have shown that bound electrons can significantly increase the decay probability. Theoretical predictions exist indicating that about 20% of ^{7}Be in the center of the Sun might have a bound electron [12, 13]. A longer lifetime of ^{7}Be in the Sun would increase the probability

Storage ring facility at HIE-ISOLDE

Technical Design Report

Table 1. Parameters of beams circulating in the TSR. See text for details.

Ion	Nuclear lifetime	Energy (MeV/u)	Cooling time	Beam lifetime in residual gas	H_2 target (atoms/cm^2)	Beam lifetime in target	Eff. target thickness (μg/cm^2)
^{7}Be 3$^+$	(53 d)	10	2.3 s	370 s			
^{18}F 9$^+$	100 m	10	0.7 s	280 s	1×10^{14}	236 s	31000
^{26m}Al 13$^+$	6.3 s	10	0.5 s	137 s	5×10^{14}	23 s	4200
^{52}Ca 20$^+$	4.6 s	10	0.4 s	58 s	5×10^{14}	9.6 s	3000
^{70}Ni 28$^+$	6.0 s	10	0.25 s	30 s	2×10^{14}	12 s	1600
^{70}Ni 25$^+$	6.0 s	10	0.3 s	26 s	2×10^{13}	2.1 s	60
^{132}Sn 30$^+$	40 s	4	0.4 s	1.5 s	1×10^{12}	1.4 s	1.2
^{132}Sn 45$^+$	40 s	4	0.2 s	1.4 s	5×10^{12}	1.6 s	7
^{132}Sn 39$^+$	40 s	10	0.25 s	7.4 s	2×10^{12}	3.6 s	9.5
^{132}Sn 45$^+$	40 s	10	0.2 s	10 s	5×10^{13}	1.3 s	90
^{186}Pb 46$^+$	4.8 s	10	0.25 s	4 s	2×10^{12}	1.5 s	4
^{186}Pb 64$^+$	4.8 s	10	0.13 s	5 s	1×10^{13}	1.7 s	20

7Be lifetime variation at different charge states is one of the hot-topics for HIE-ISOLDE storage ring

An exciting possibility: study of bound-β decay in a high-energy content plasma

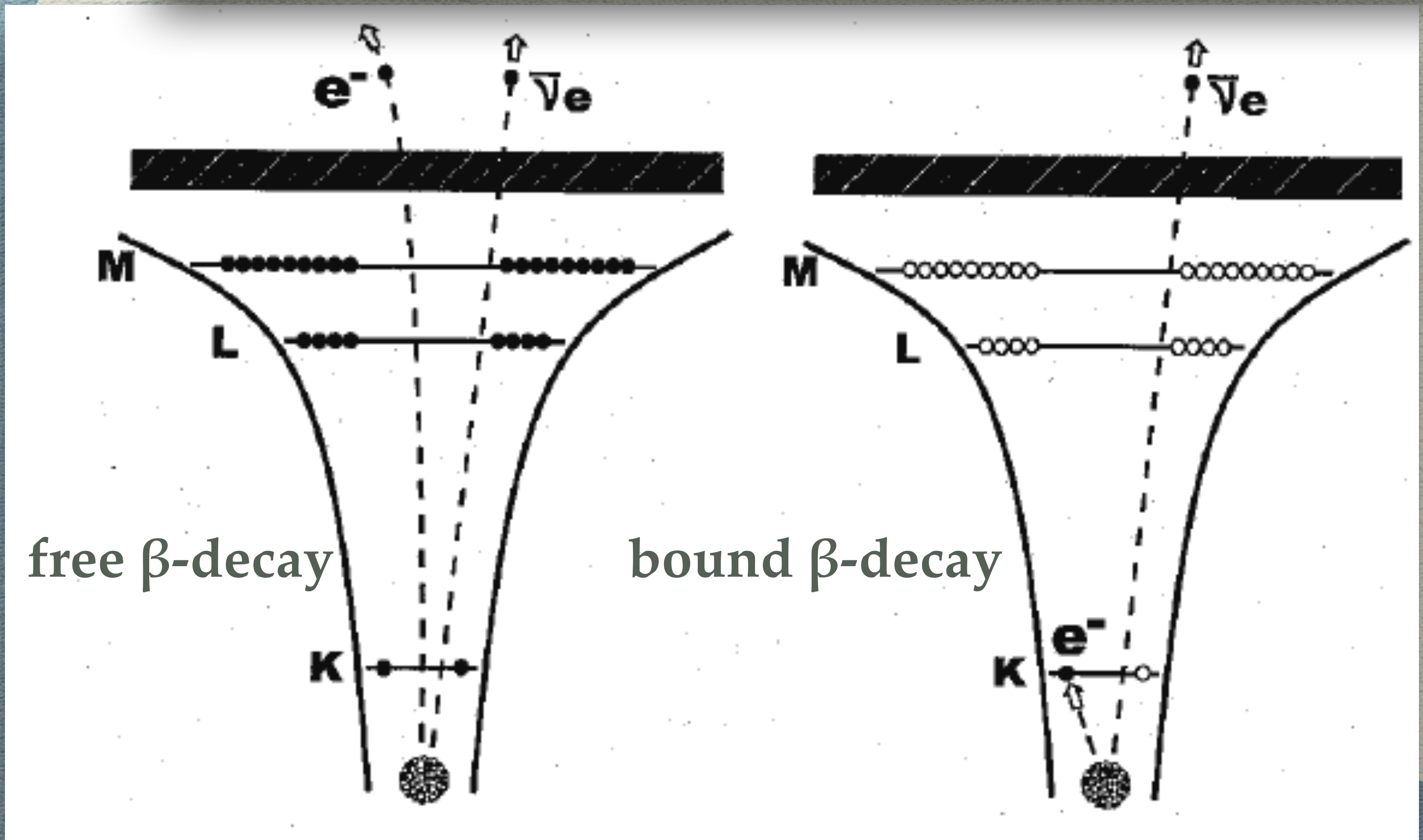
Physica Scripta

Manipulation of nuclear lifetimes in storage rings

Fritz Bosch

Physica Scripta, Volume 1995, T59

value lead to a halflife of 42 x 10^9 y. For *fully ionized* ^{187}Re the continuum β^- decay is forbidden (negative Q value), whereas bound-state β^- decay with the electron bound in the K shell becomes possible. The dominant decay branch, a nonunique first forbidden transition, feeds the *first excited state* in ^{187}Os at 9.75 keV excitation energy. This effect dramatically decreases the half-life of bare ^{187}Re, as measured at the ESR (see next section), to 33 y only. The figure is taken from [42].



^{187}Re can be multi-ionized and trapped in an ECR machine: the S.R. observed lifetime variation of 9 orders of magnitude (!!)

LETTER

doi:10.1038/nature24298

Spectroscopic identification of r-process nucleosynthesis in a double neutron-star merger

E. Pian[1], P. D'Avanzo[2], S. Benetti[3], M. Branchesi[4,5], E. Brocato[6], S. Campana[2], E. Cappellaro[3], S. Covino[2], V. D'Elia[6,7], J. P. U. Fynbo[8], F. Getman[9], G. Ghirlanda[2], G. Ghisellini[2], A. Grado[9], G. Greco[10,11], J. Hjorth[8], C. Kouveliotou[12], A. Levan[13], L. Limatola[9], D. Malesani[8], P. A. Mazzali[14,15], A. Melandri[2], P. Møller[16], L. Nicastro[1], E. Palazzi[1], S. Piranomonte[6], A. Rossi[1], O. S. Salafia[2,17], J. Selsing[8], G. Stratta[10,11], M. Tanaka[18], N. R. Tanvir[19], L. Tomasella[3], D. Watson[8], S. Yang[20,21], L. Amati[1], L. A. Antonelli[6], S. Ascenzi[6,22,23], M. G. Bernardini[2,24], M. Boër[25], F. Bufano[26], A. Bulgarelli[1], M. Capaccioli[9,27], P. Casella[6], A. J. Castro-Tirado[28], E. Chassande-Mottin[29], R. Ciolfi[3,30], C. M. Copperwheat[14], M. Dadina[1], G. De Cesare[1], A. Di Paola[6], Y. Z. Fan[31], B. Gendre[32], G. Giuffrida[6], A. Giunta[6], L. K. Hunt[33], G. L. Israel[6], Z.-P. Jin[31], M. M. Kasliwal[34], S. Klose[35], M. Lisi[6], F. Longo[36], E. Maiorano[1], M. Mapelli[3,37], N. Masetti[1,38], L. Nava[2,39], B. Patricelli[40], D. Perley[14], A. Pescalli[2,41], T. Piran[42], A. Possenti[43], L. Pulone[6], M. Razzano[40], R. Salvaterra[44], P. Schipani[9], M. Spera[3], A. Stamerra[40,45], L. Stella[6], G. Tagliaferri[2], V. Testa[6], E. Troja[46], M. Turatto[3], S. D. Vergani[2,47] & D. Vergani[1]

"Stars in Jar" → The issue of astrophysical plasma opacities

In-laboratory measurements in the MULTIMESSANGER era

The Astrophysical Journal, 774:25 (13pp), 2013 September 1

doi:10.1088/0004-637X/774/1/25

OPACITIES AND SPECTRA OF THE *r*-PROCESS EJECTA FROM NEUTRON STAR MERGERS

Daniel Kasen[1,2], N. R. Badnell[3], and Jennifer Barnes[1,2]
[1] Department of Physics and Astronomy, University of California, Berkeley, CA 94720, USA
[2] Nuclear Science Division, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, USA
[3] Depa
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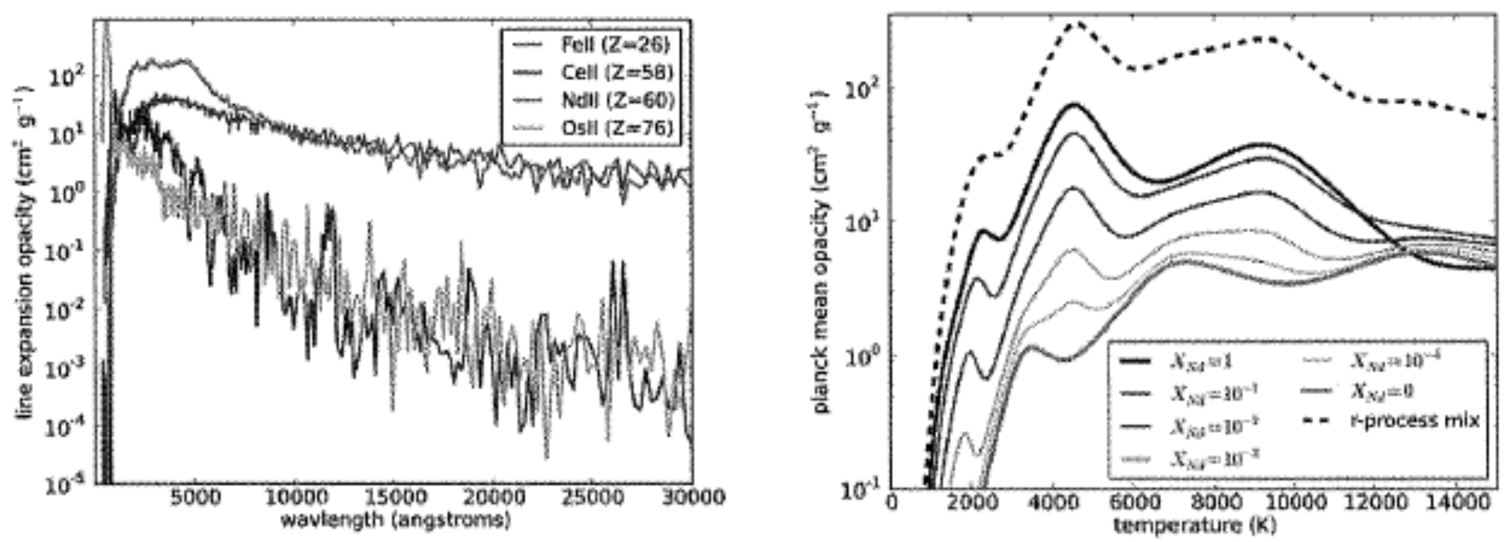


Figure 2: **Left:** Line opacity as a function of wavelength, comparing elements with d-shell valence shell electrons (iron, cerium) to lanthanides with f-shell electrons (e.g. Nd, Os). **Right:** Planck mean opacities, $\kappa_{\rm Pl} = \frac{\int_0^\infty \kappa_\nu B_\nu(T) d\nu}{\int_0^\infty B_\nu(T) d\nu}$, for ejecta containing different mass fractions of lanthanides $X_{\rm Nd}$, the remainder being non-lanthanides $X_{\rm Fe} = 1 - X_{\rm Nd}$. From Kasen et al. (2013).

"Stars in the Jar"
the PANDORA project

Plasmas for Astrophysics, Nuclear Decays Observation and Radiation for Archaeometry

INFN
Istituto Nazionale di Fisica Nucleare

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Fertile network of collaborations

INFN
Istituto Nazionale di Fisica Nucleare

INFN-LNS
Plasma studies

INFN-LNL
Beam-plasma studies

INFN-LNS
Nucl. Exp. aspects

INFN-Pg
Theory

INFN-other section interested (Bo, Ts, Ge)

University of Michigan
University of Cambridge

INAF
Istituto Nazionale di Astrofisica
National Institute for Astrophysics

Collaborations

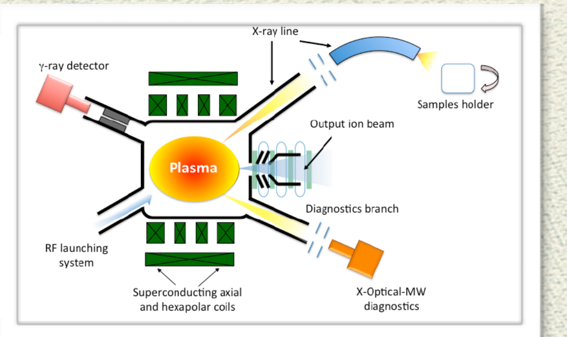
Goethe Universität Frankfurt am Main

MTA atomki Debrecen

GANIL
Grand Accelerateur National d'Ions Lourds
Laboratoire commun DSM/CEA-IN2P3/CNRS

LPSC Grenoble
Laboratoire de Physique Subatomique et de Cosmologie

Paul Scherrer Institut
PSI



Plasmas for Astrophysics, Nuclear Decays Observation and Radiation for Archaeometry

PANDORA's challenges

Relevant Budget for the realization of the superconducting trap

1. On-Line Measurements of n, T, CSD of the plasma

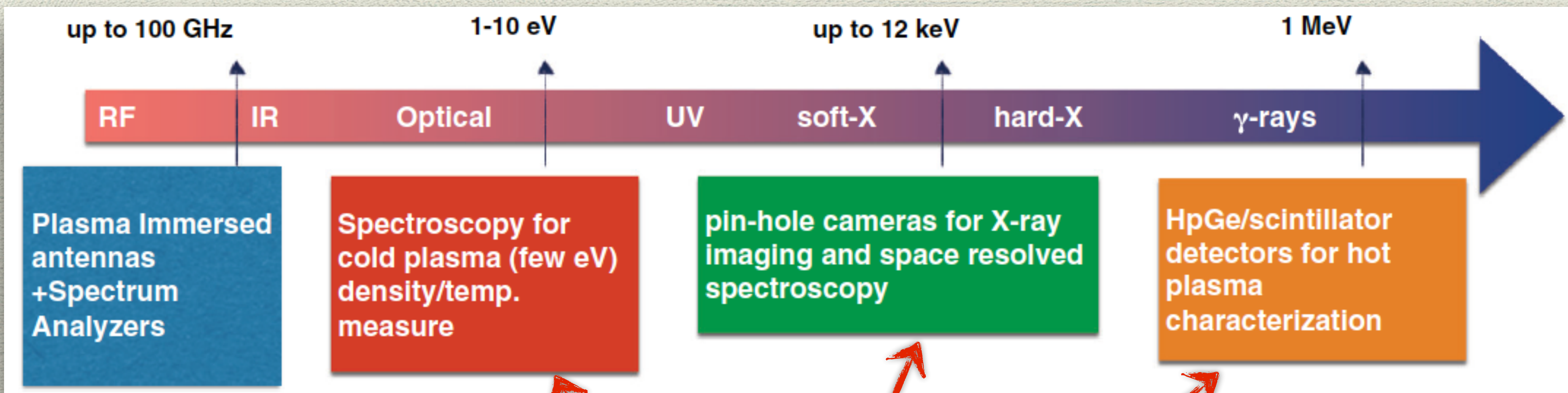
\+

2. Radioisotopes handling and injection into the plasma trap

PANDORA feasibility study

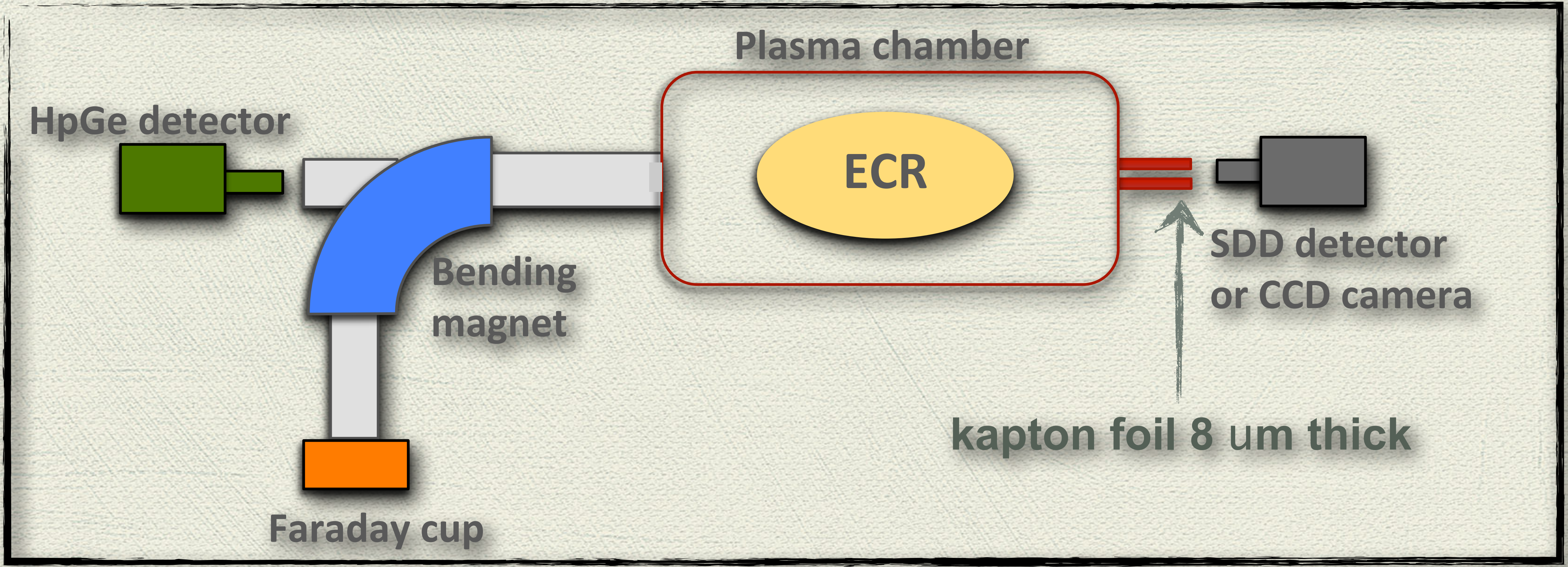
READY for Multidiagnostics operations!!

Non-intrusive plasma diagnostics methods

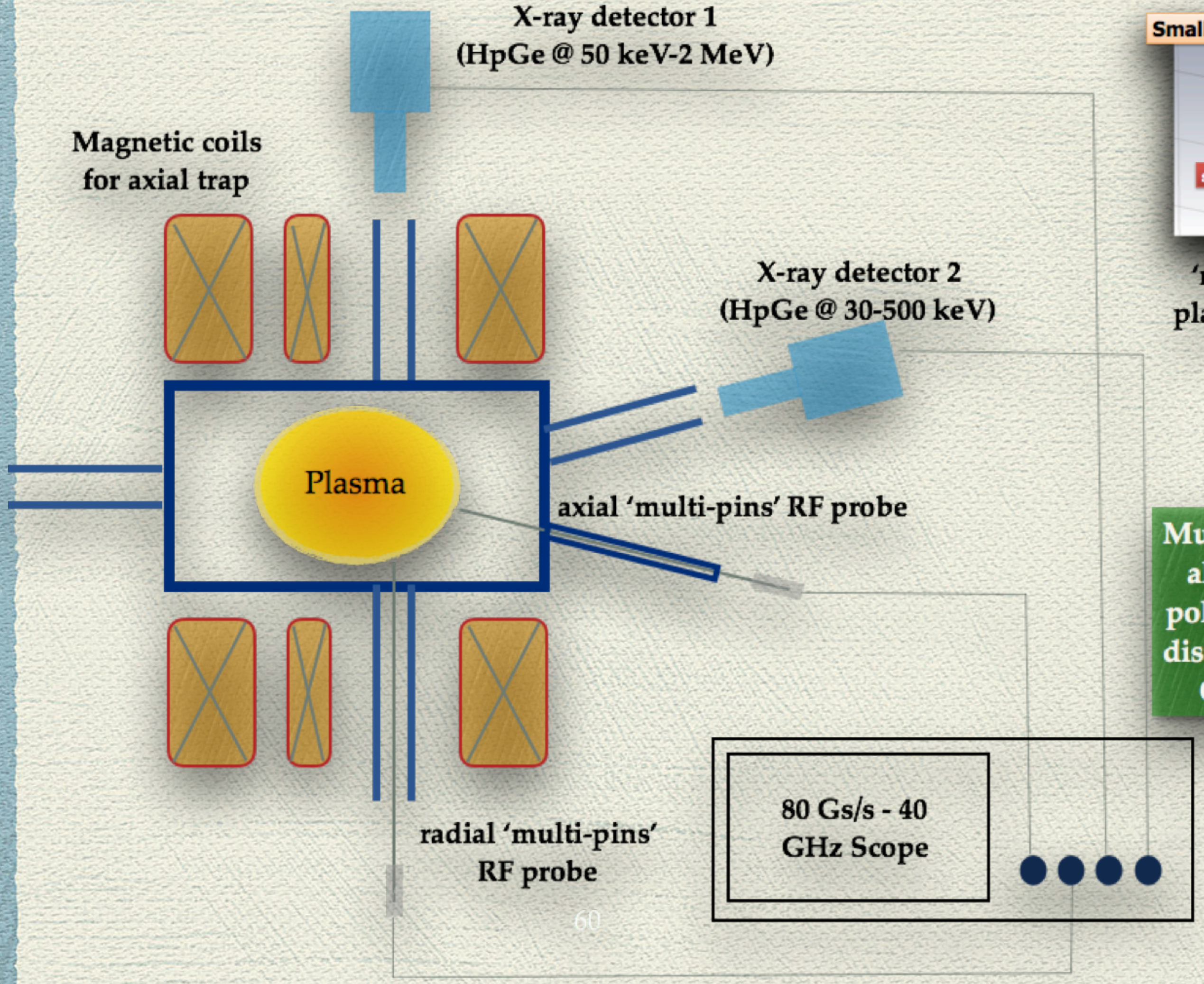


Measuring the plasma density in different energy regimes: density, temperature and plasma structure evaluation under different operative parameters

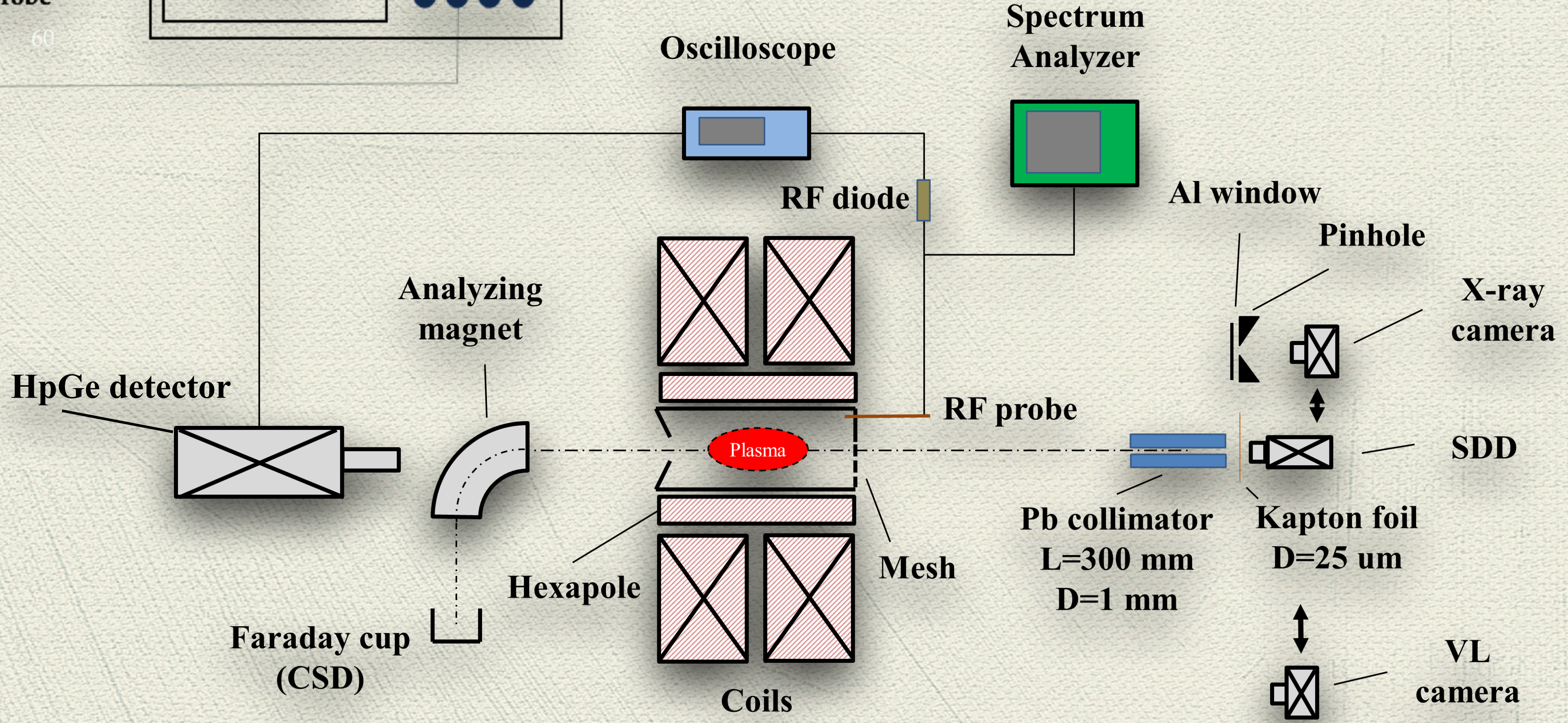
Experimental setup for simultaneous measurement of density, temperature and CSD



- Three detectors were used for a broad characterization of the EEDF:
  - HpGe for "hot electrons" E>30 keV
  - SDD for "warm electrons" 2<E<30 keV
  - CCD camera for imaging and 2D resolved spectroscopy 1<E<10kEV



Experimental setups for SPACE and TIME-resolved characterization of magnetoplasmas in compact traps, including kinetic turbulences



[see also E. Naselli et al. poster presentation, this conf.]

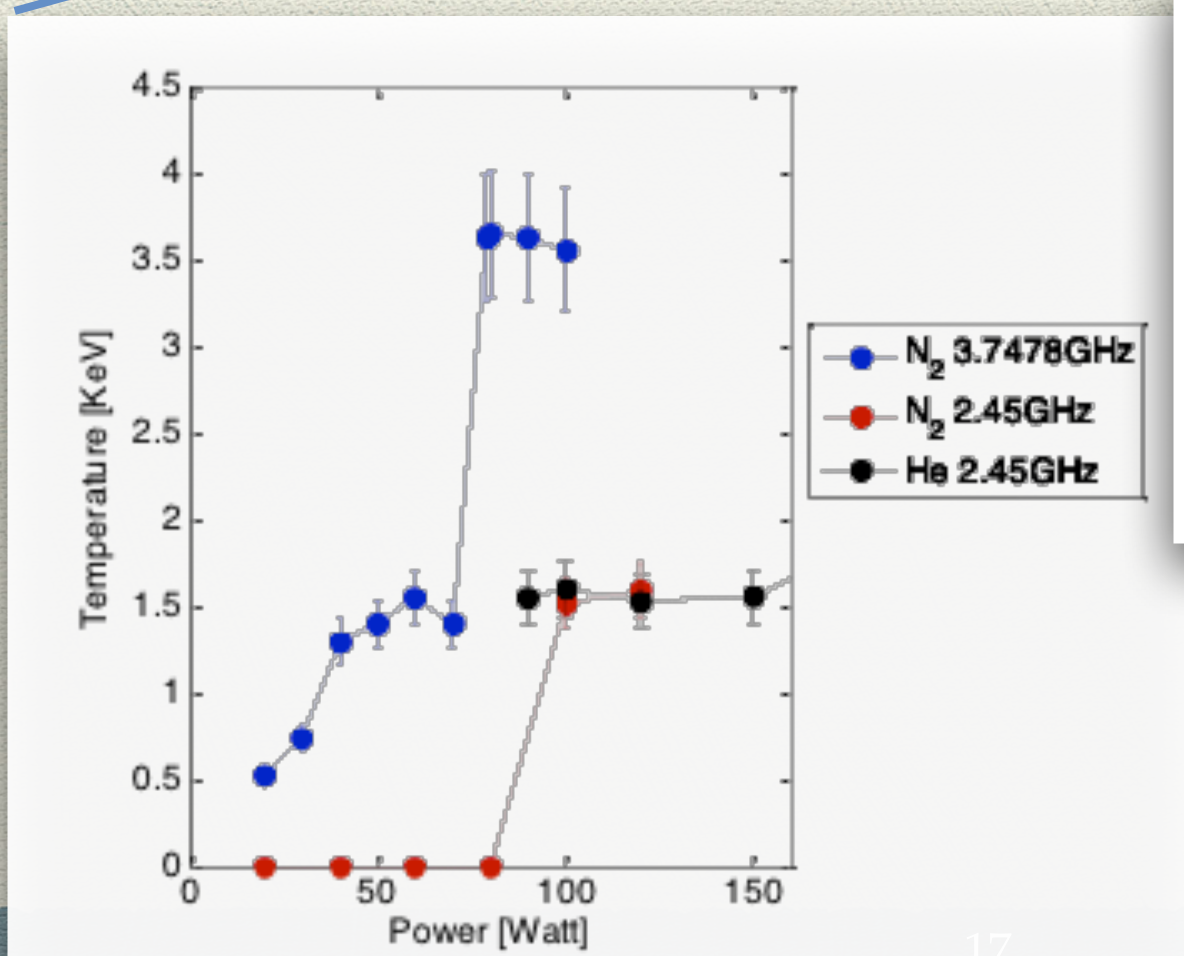
Non-intrusive plasma diagnostics methods

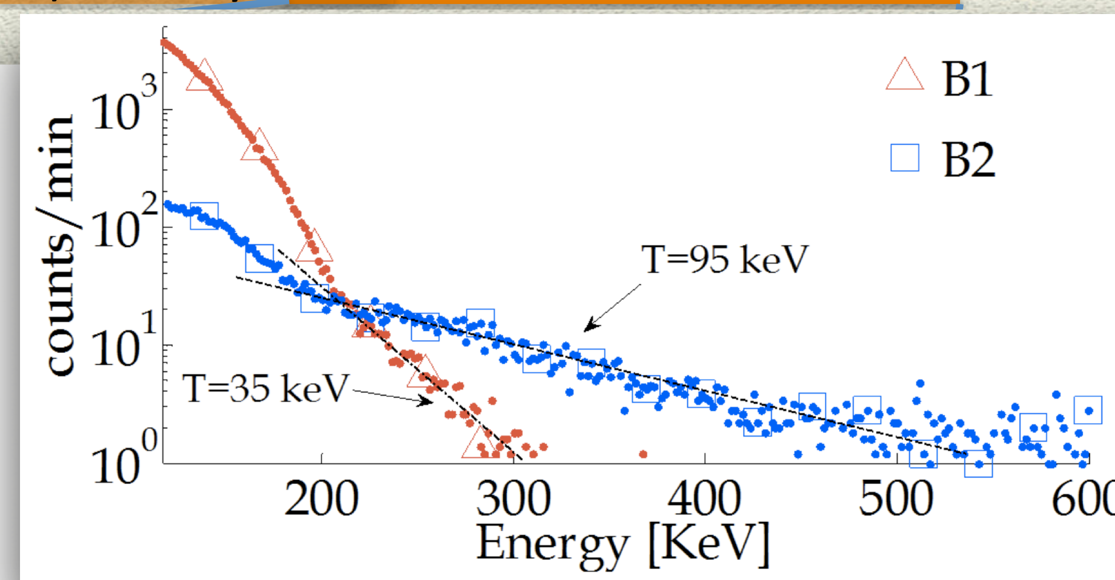
RF	IR	Visible & UV	EUV	Soft-Xray	Hard-Xray
(3 kHz-300 GHz)	(300 GHz-430 THz)	(1,6-12 eV)	(10-120 eV)	(0,12-12 keV)	(10-100 keV)

Optical plasma Observation
Spectroscopy 1D/2D
density-temp. measurement

X-ray Pinhole Camera
Imaging & 2D-Spectroscopy
2D energy distribution and (relative) density

SDD - HpGe X-ray detectors
Spectroscopy





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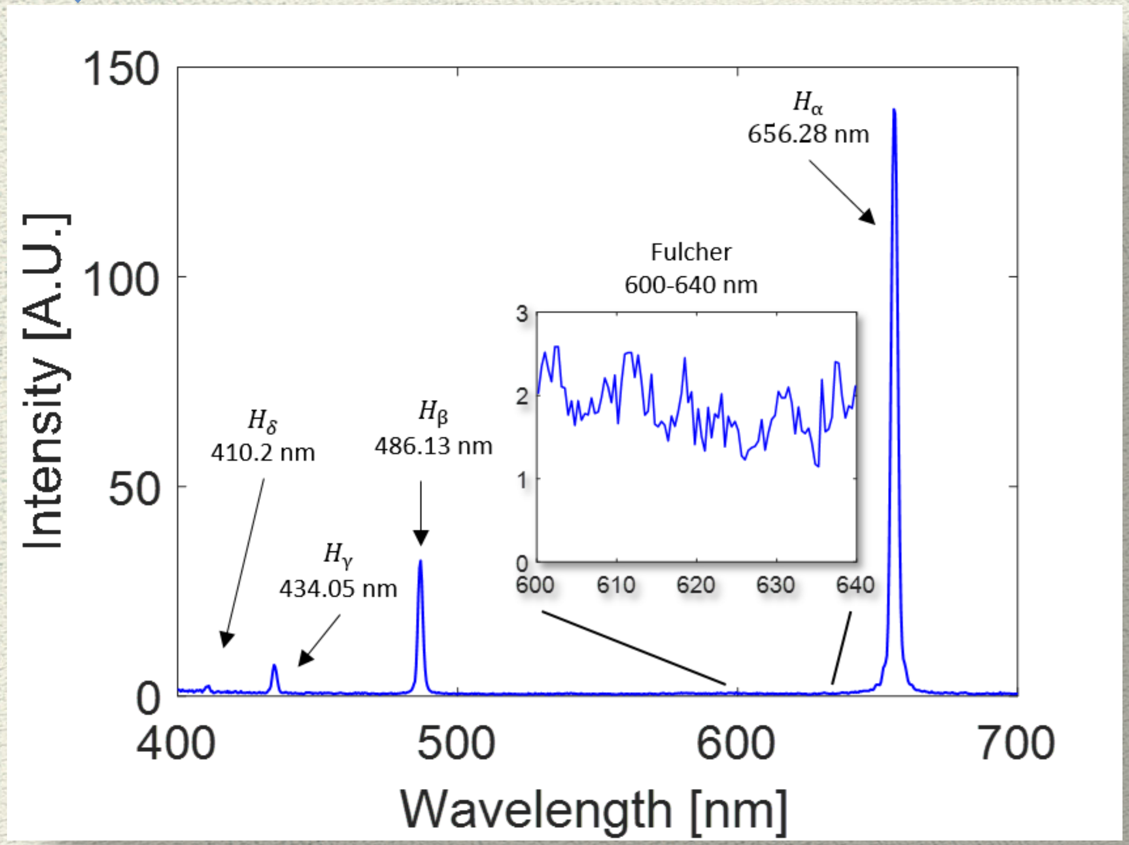
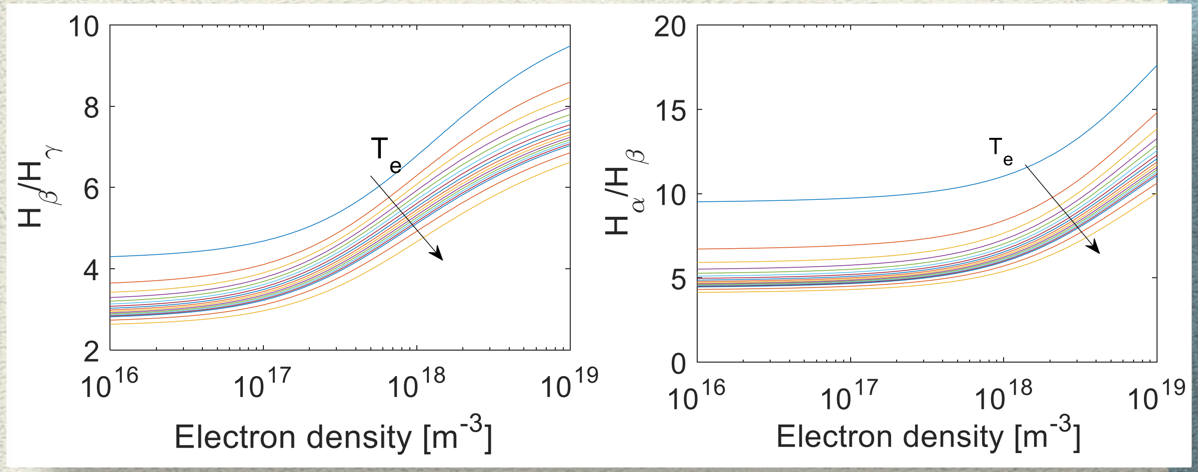
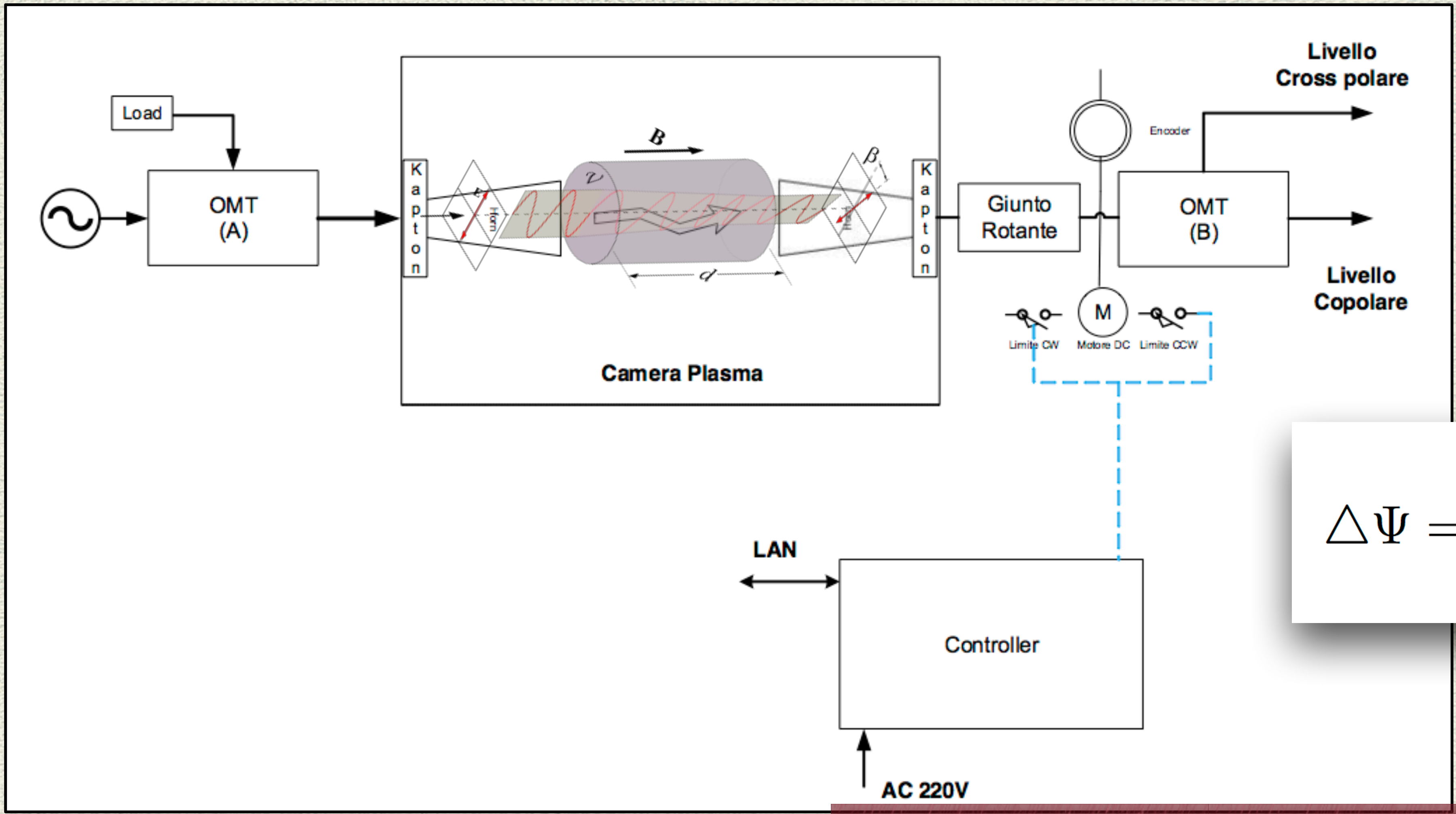




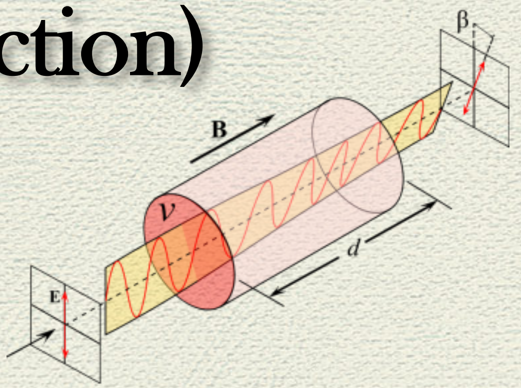
U. Fantz, Plasma Sources Sci. Technol. 15, p. S137 (2006).

Faraday rotation measurements

Next step Polarimetry (Faraday rotation detection)



Setup Block Diagram

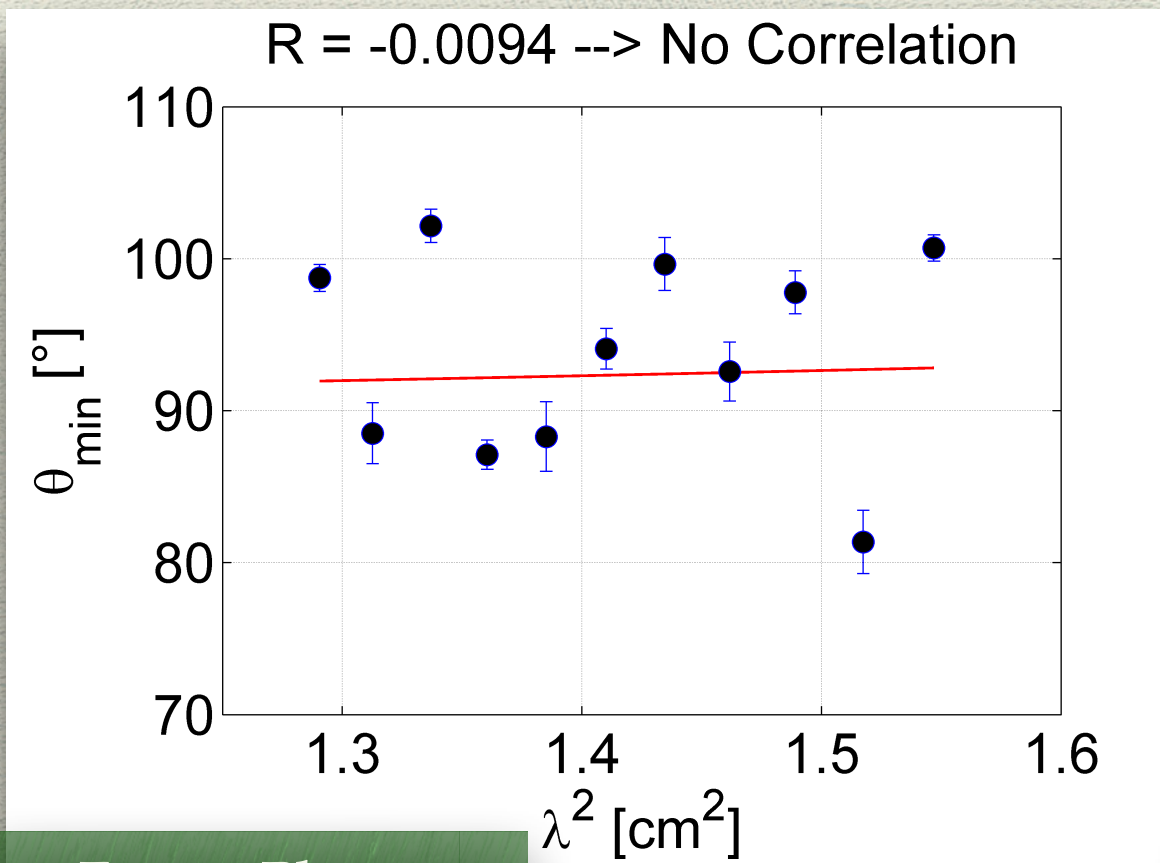


$$\triangle\Psi = \frac{e^3\lambda^2}{2\pi m_e^2 c^4}\int_0^L n_e(l)B_{\parallel}(l).dl$$

The polarimetric system has been designed jointly with SICIL-Sat s.r.l. (satellite communications)

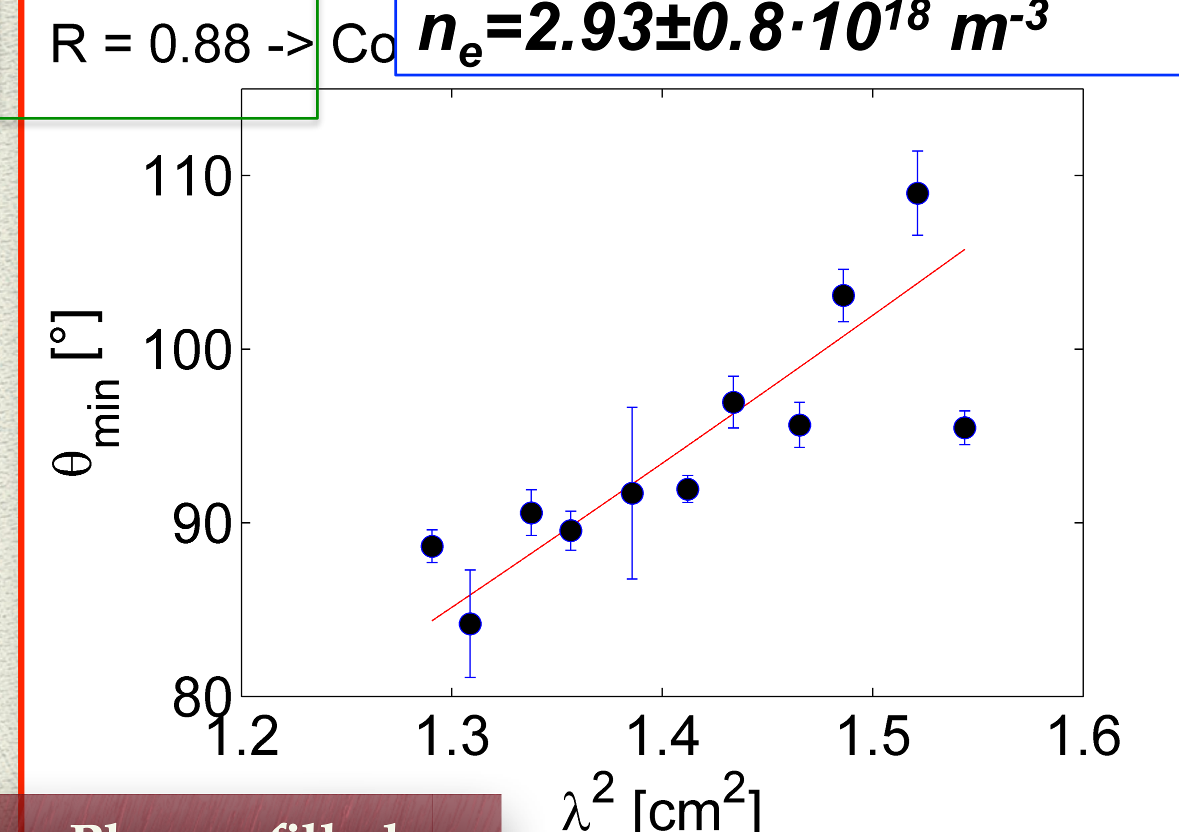
Faraday rotation measurements

Fitting procedure



Empty Plasma Chamber

Estimated plasma density:
n_e=2.93±0.8·10^18 m^{-3}



Plasma filled Chamber

Experimental data have been **fitted** with statistical consistence **by a λ^2 law, in agreement with Faraday rotation** dependence on the probing wave-length

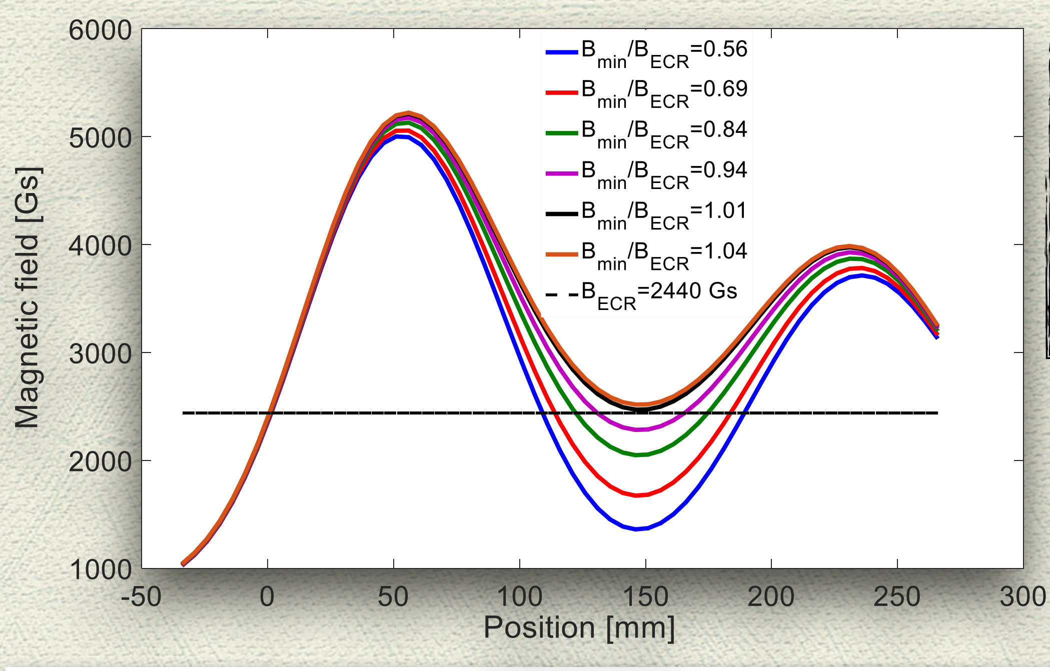
wavelength

$$\theta = \frac{q_e^3}{8\pi^2 c^3 m_e^2 \varepsilon_0} Bd\ n_e \lambda^2$$

Magnetic field

plasma density

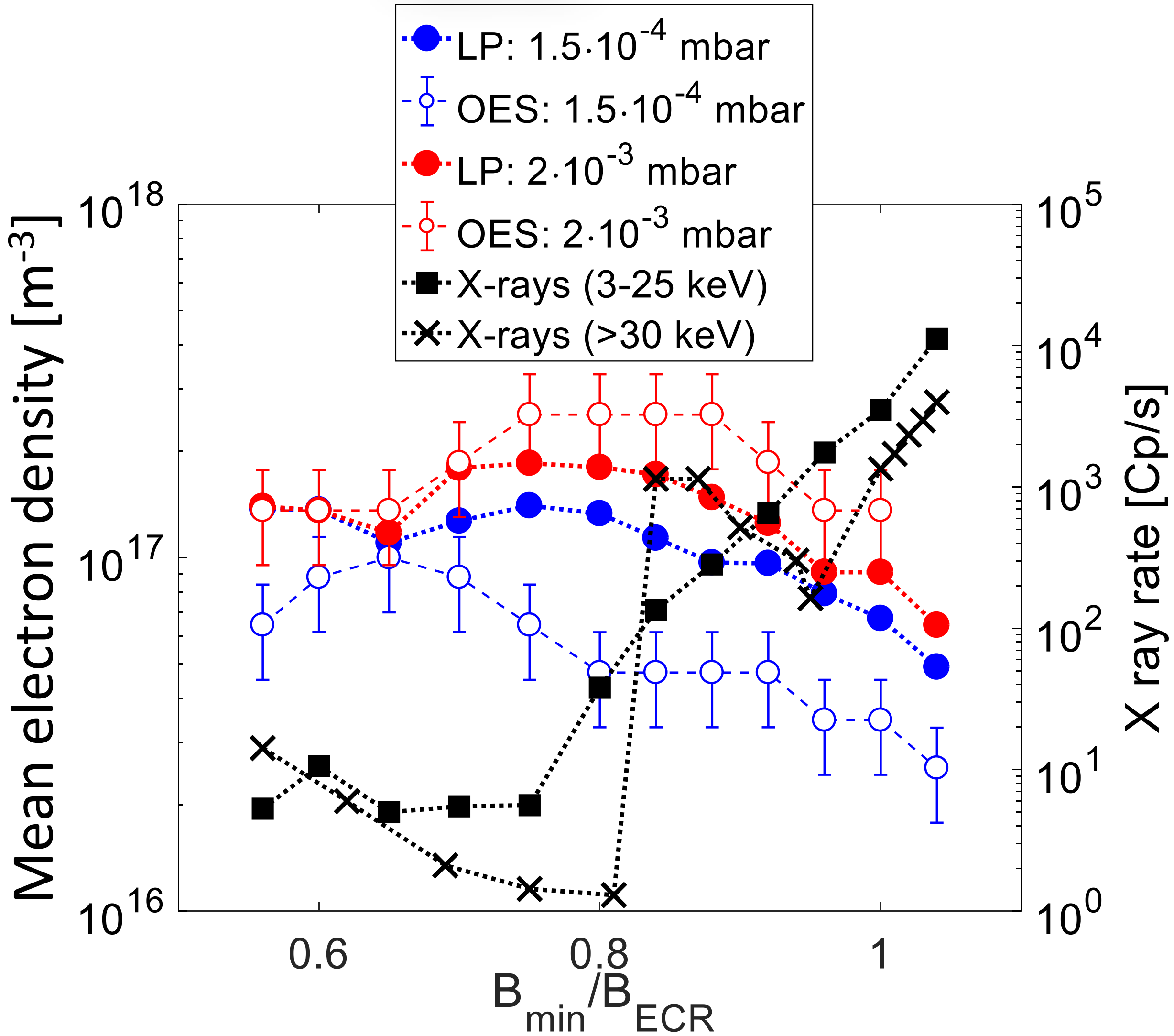
E. Naselli et al., *The first measurement of plasma density by means of an interfero-polarimetric setup in a compact ECR-plasma trap* **SIF 2018, Otal talk Wednsday moring**

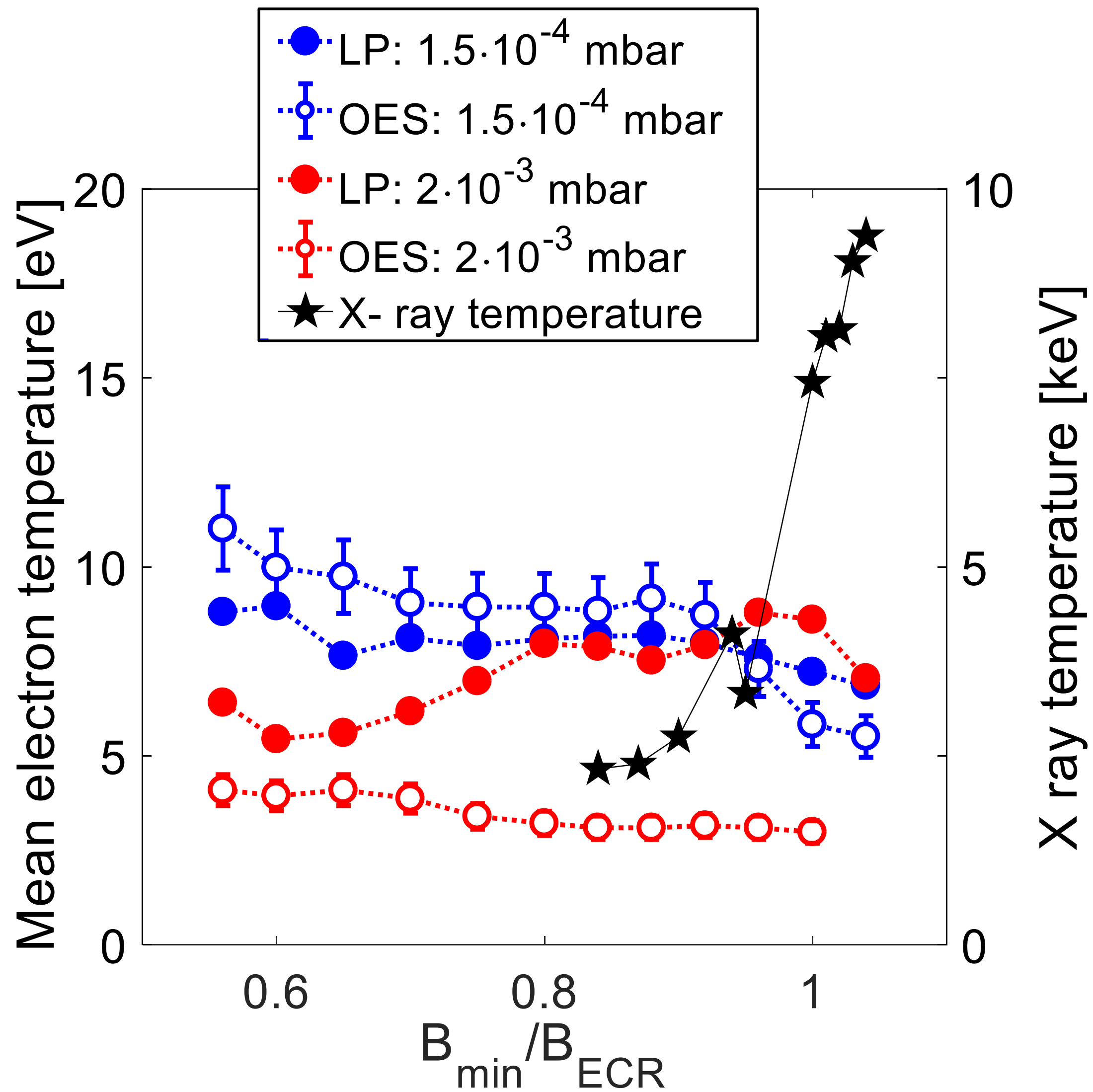


Multidiagnostics including OES for studying cold electrons

recently presented at ICIS17-Geneva

Data seem to say temperature and abundances of warm/hot electrons depend mostly from axial gradients





In collaboration with Max Plank Institute – Institute of Plasma Physics (Germany)

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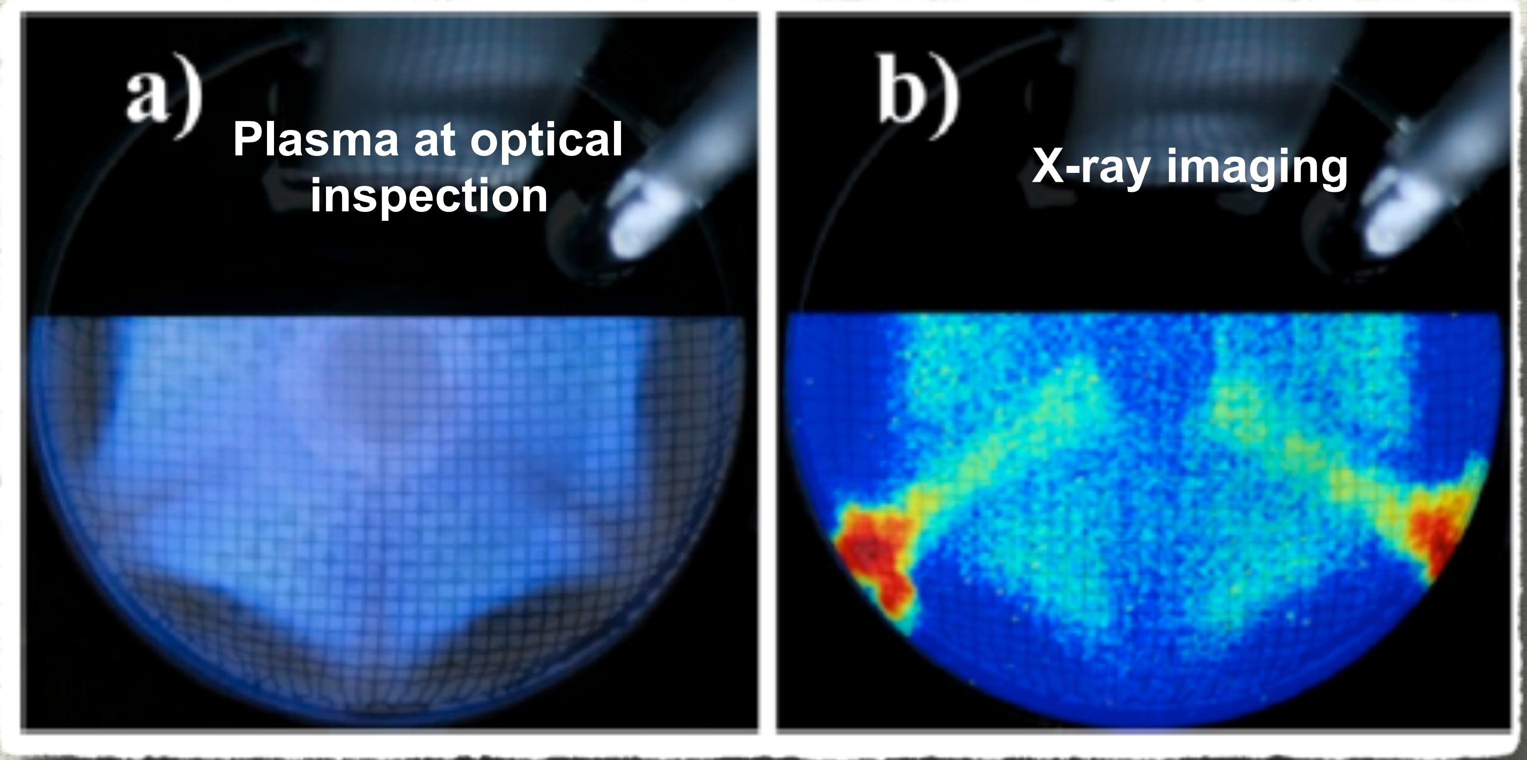
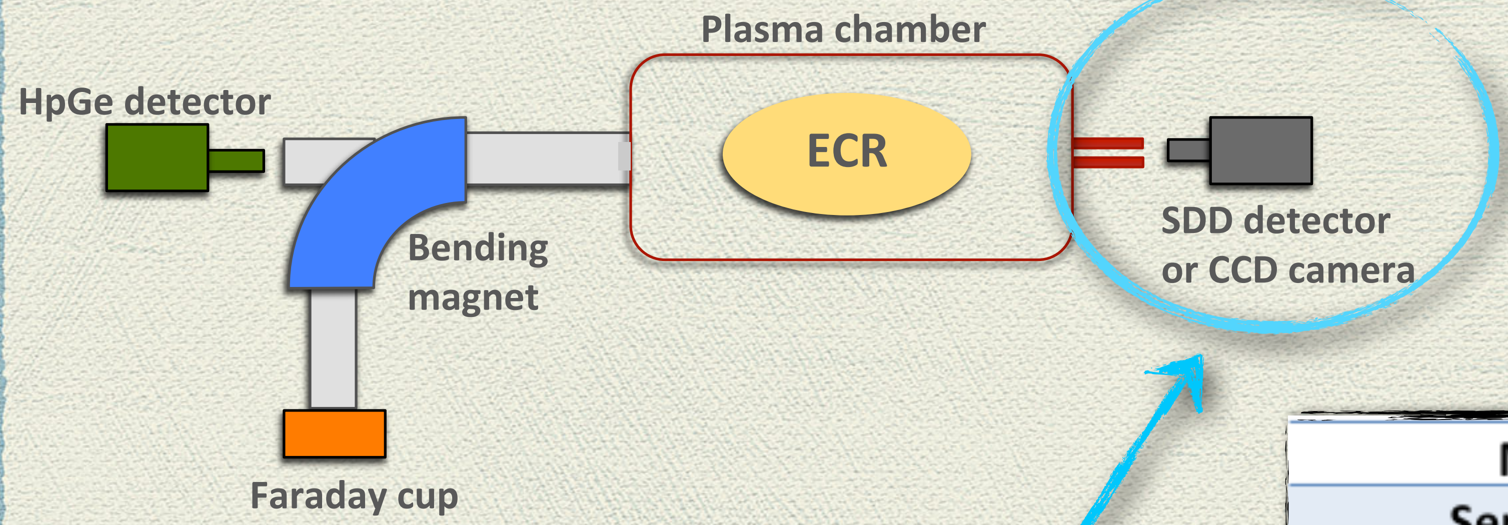
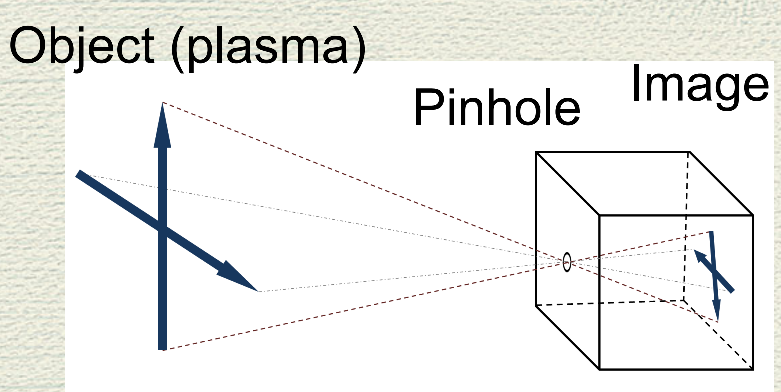
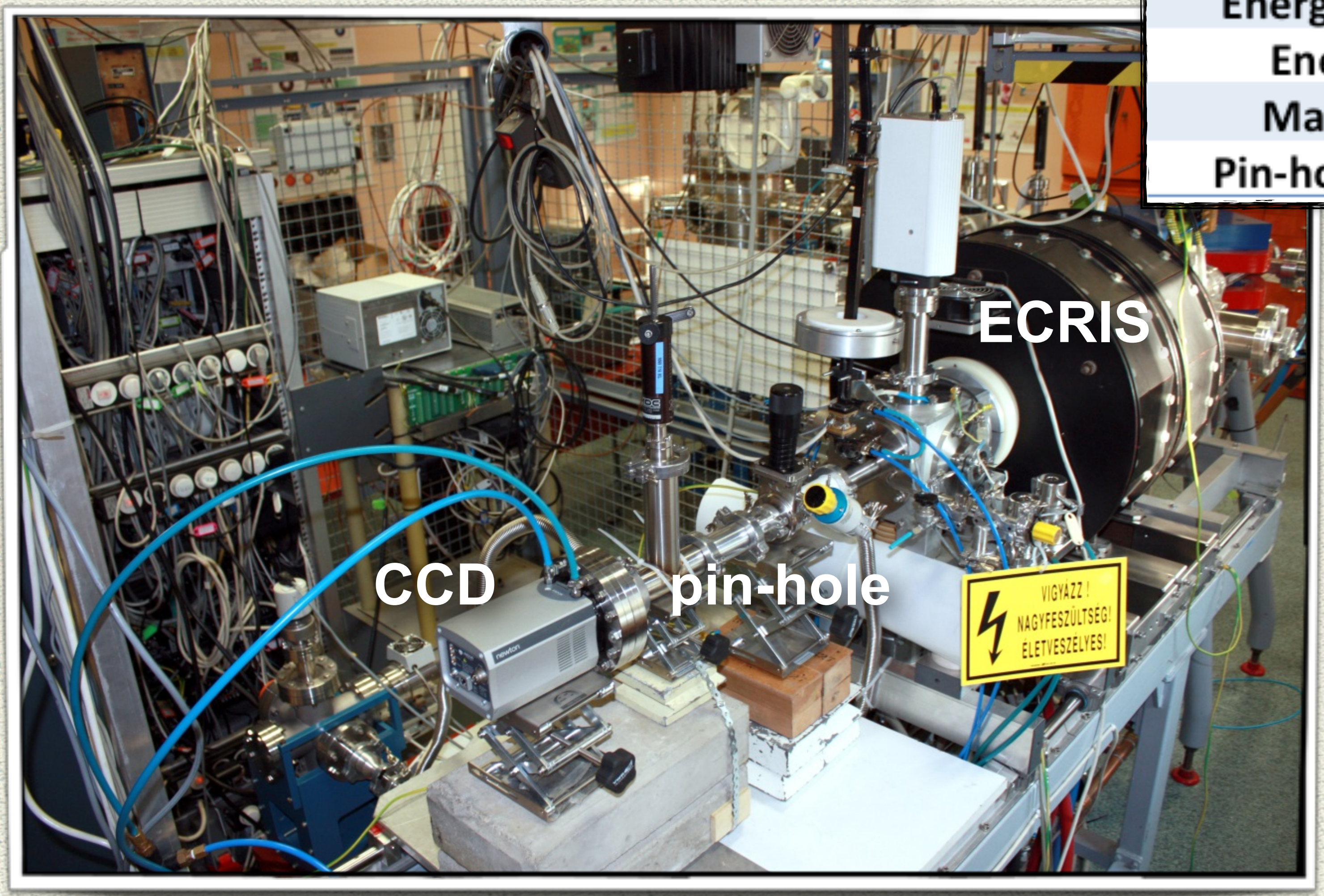


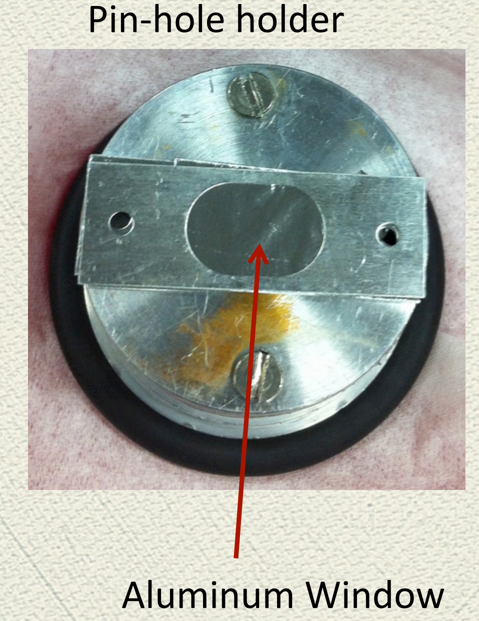
CCD camera Set-up



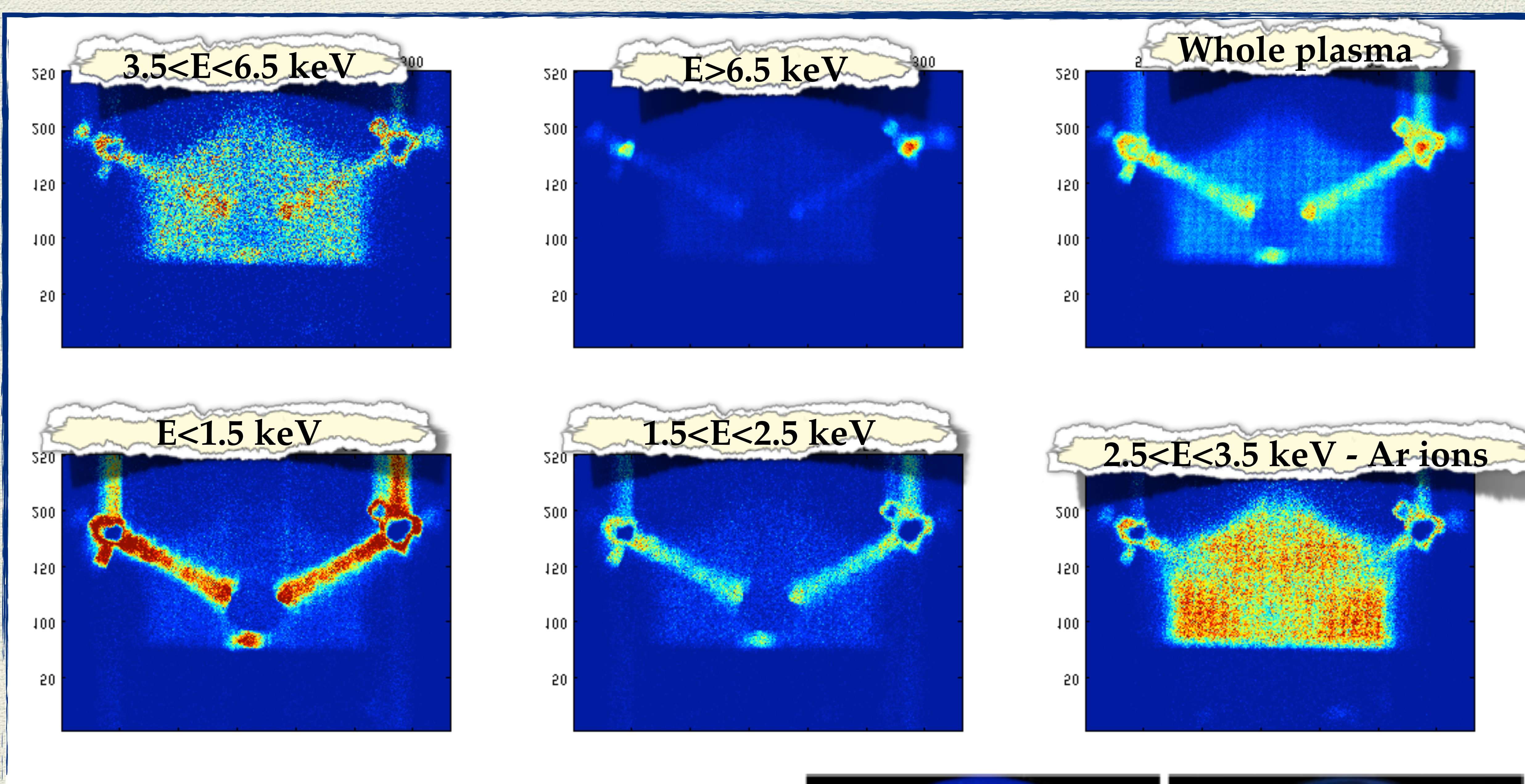


Model	Andor Technology - Newton
Sensor size	27.6 mm x 6.9 mm
Pixels	1024 x 255 (0.3 MP)
Energy Resolution	150 eV
Energy range	1-10 keV
Magnification	0.082-0.124-0.158
Pin-hole diameters	75 um and 100 um (W and Pb)





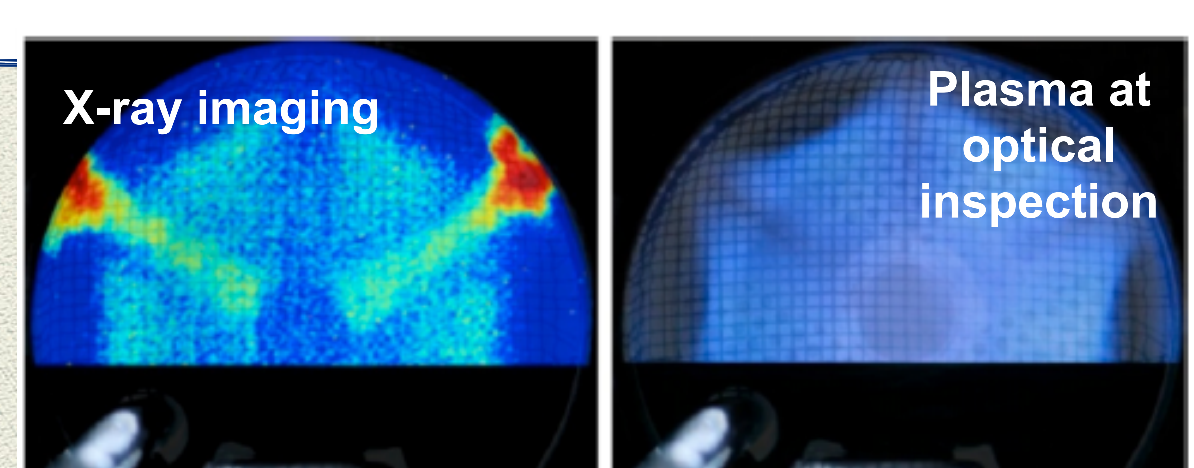
Plasma inspection after energy filtering



IOP Publishing
Plasma Sources Science and Technology
Plasma Sources Sci. Technol. 26 (2017) 075011 (14pp)
https://doi.org/10.1088/1361-6595/aa758f

Electron cyclotron resonance ion source plasma characterization by energy dispersive x-ray imaging

R Rácz[1,5], D Mascali[2], S Biri[1], C Caliri[2], G Castro[2], A Galatà[3], S Gammino[2], L Neri[2], J Pálinkás[1], F P Romano[4] and G Torrisi[2]



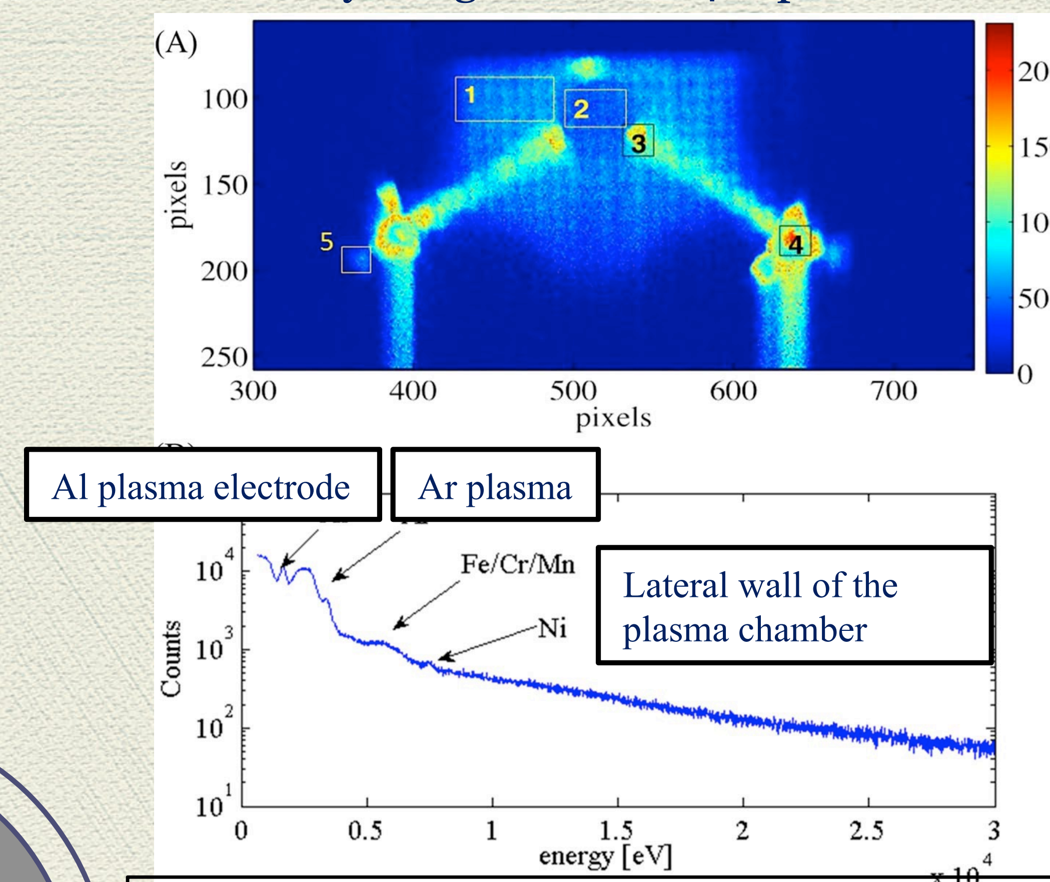
24

Advanced design of the plasma chamber walls oriented to spatially-resolved X-ray spectroscopy

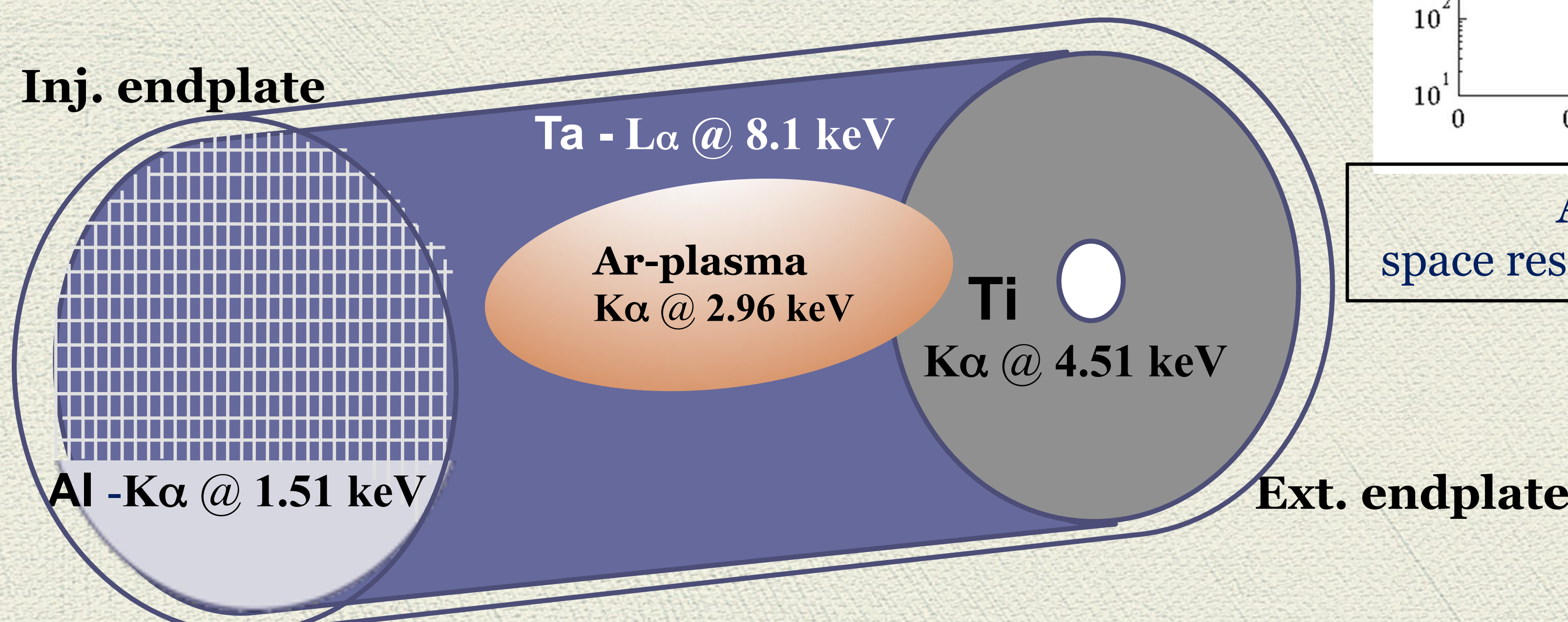
Measurements in 2014 show that fluorescence lines can be used to get info about where the electrons collide on the chamber walls!

Now, in order to have well separated component of the emitted X-ray:
→ special design of plasma chamber for studying confinement dynamics
(plasma vs. losses X-radiation emission)

X-ray image from 2014 experiment



Already in 2014 PhC X-ray space resolved-spectroscopy was performed

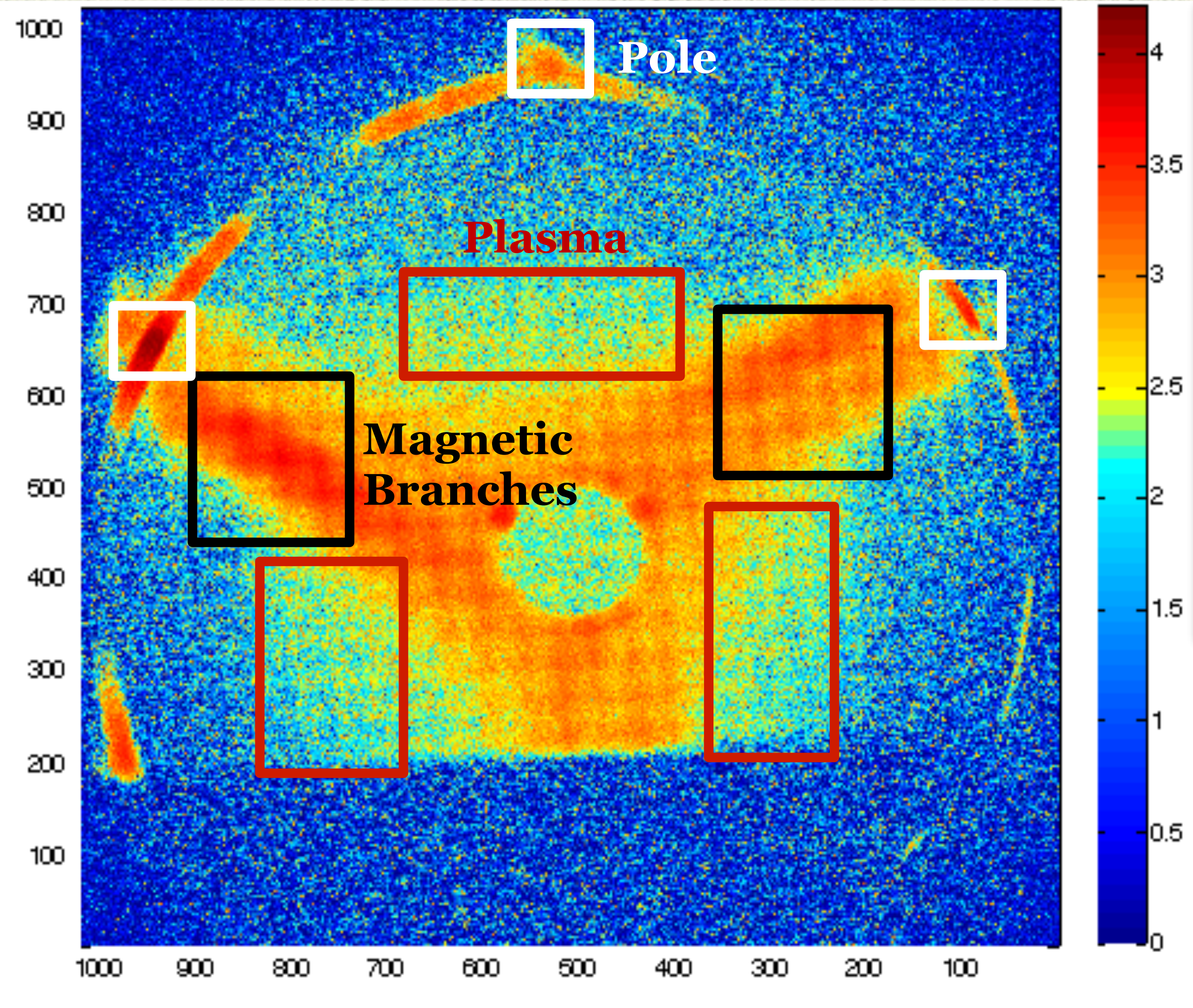


R. Racz et al. Plasma Sources Science and Technology, Vol. 26, No. 7
*D. Mascali et al., Review of Scientific Instruments **87**, 02A510 (2016)*

Advanced design of the plasma chamber walls oriented to spatially-resolved X-ray spectroscopy

High-spatial resolution, time integrated images with an **exposure time of 50 sec**

→ **Counts estimated in each ROI rely to n·E, i.e. including both photon flux and energy content**



X-rays coming from magnetic branches consist of mostly fluorescence from Ti

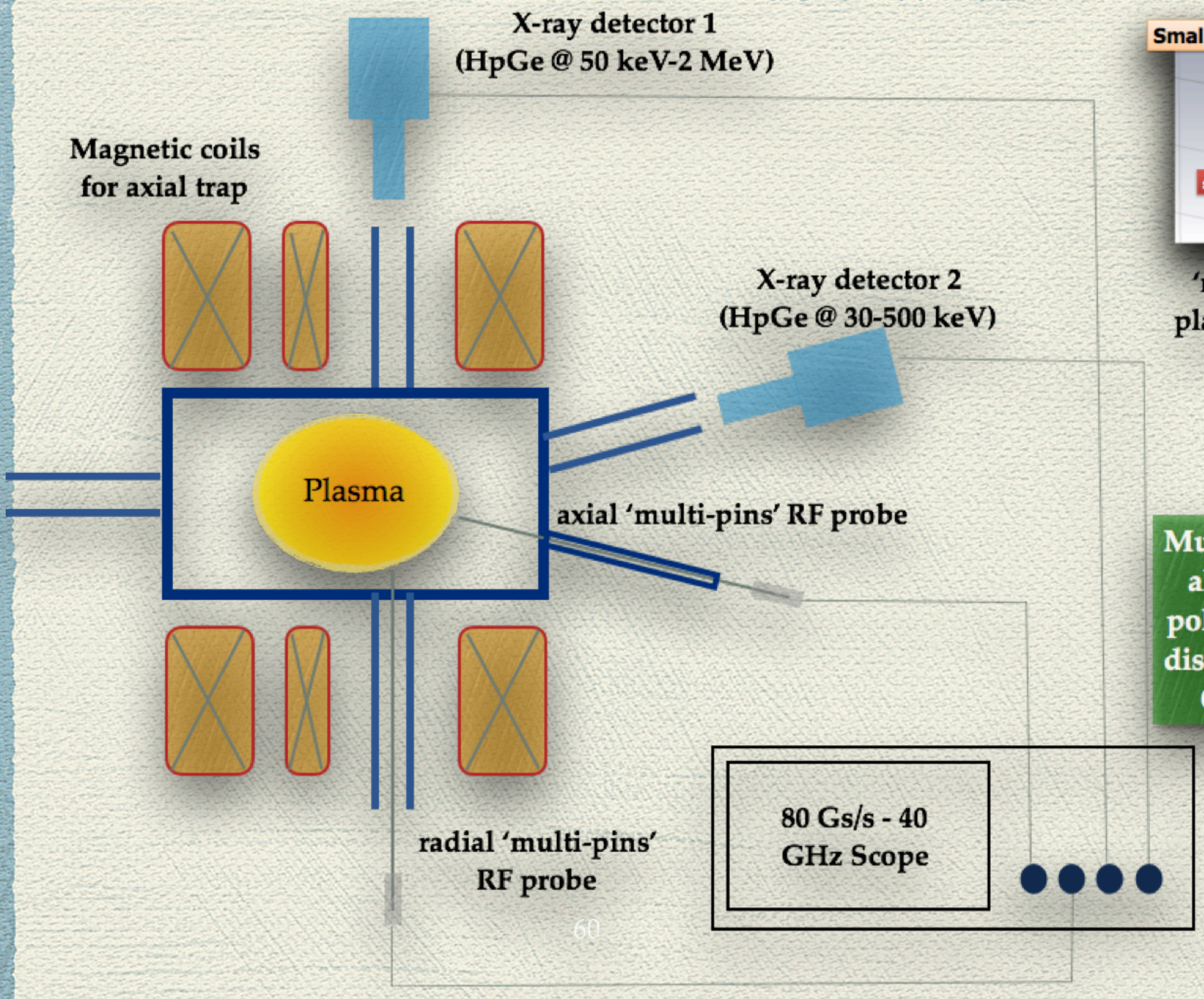
X-rays coming from plasma are mostly due to ionized Kα Argon lines

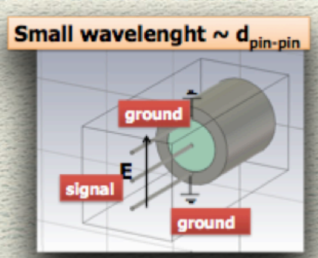
X-rays coming from poles are mostly due to radial losses impinging on the Ta liner

Flux in Branches+Poles=**LOSSES**
Flux in red rectangles: **PLASMA**

Decoupling of n vs E will possible only after the spectral analysis (already acquired but not yet elaborated)

Experimental setup for time-resolved characterization of a turbulent plasma

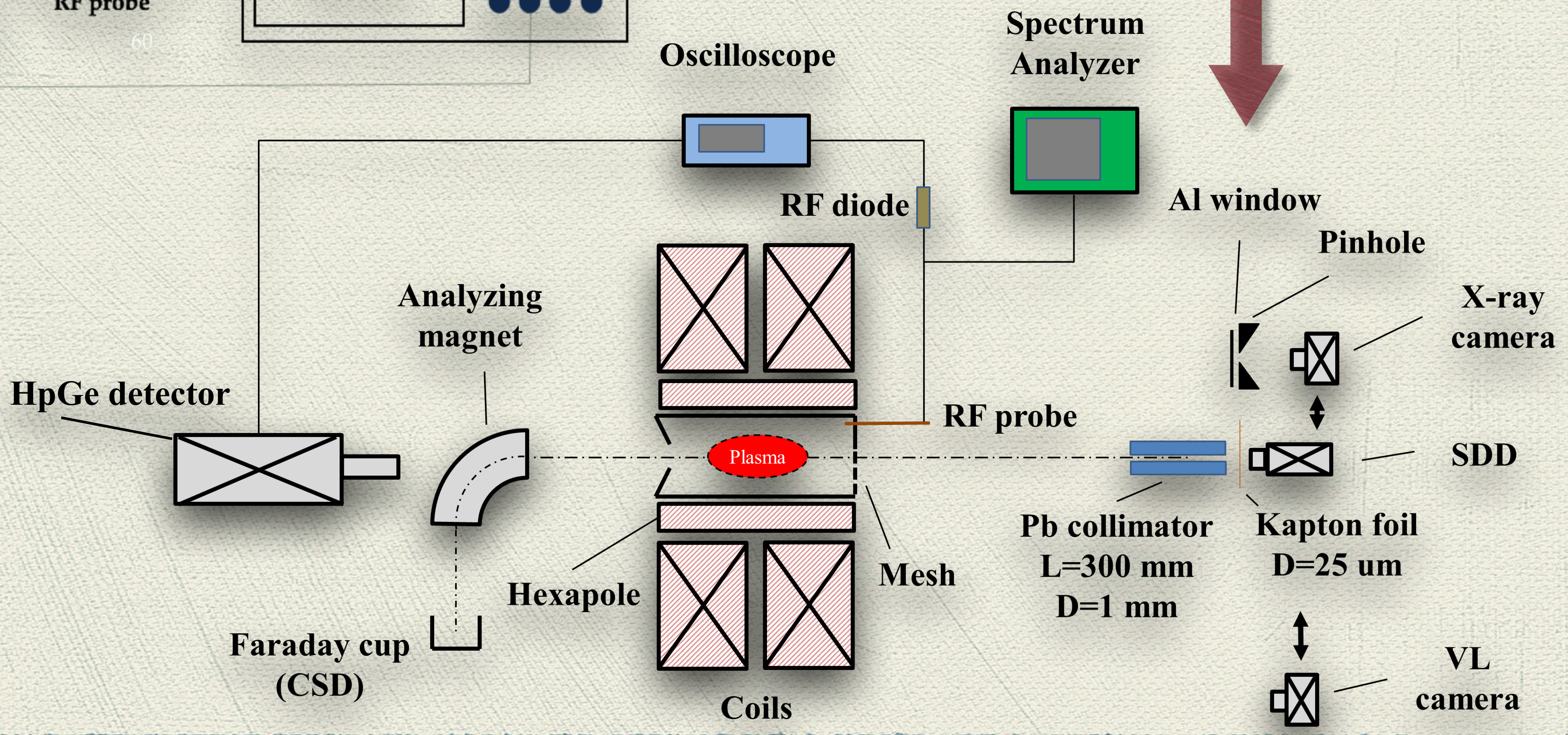




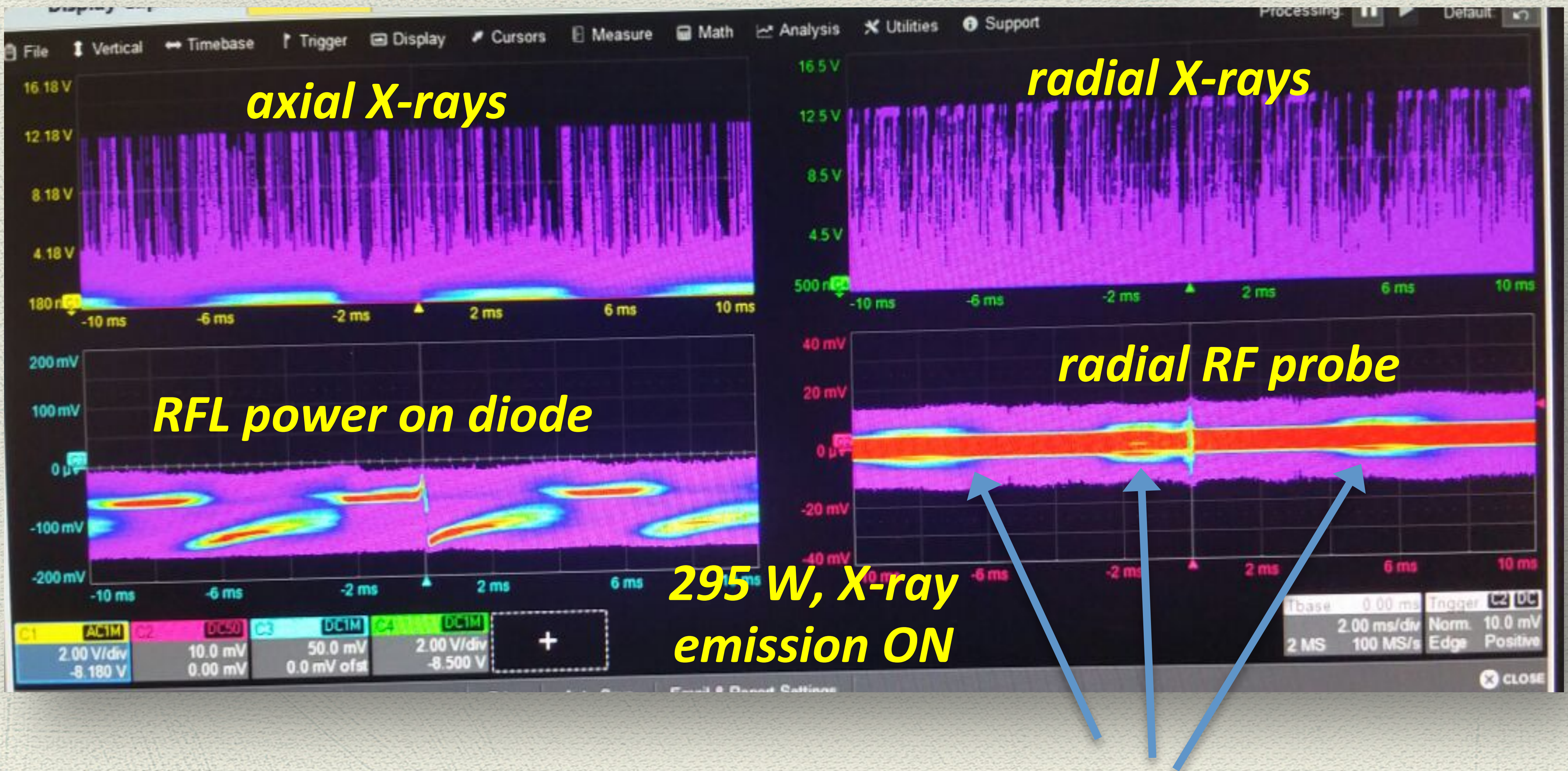
'multi-pins' RF plasma immersed probes

Multi-pin RF probes allow to measure polarization: how to distinguish between O and X modes

Experimental setup for SPACE and TIME-resolved characterization of a turbulent plasma

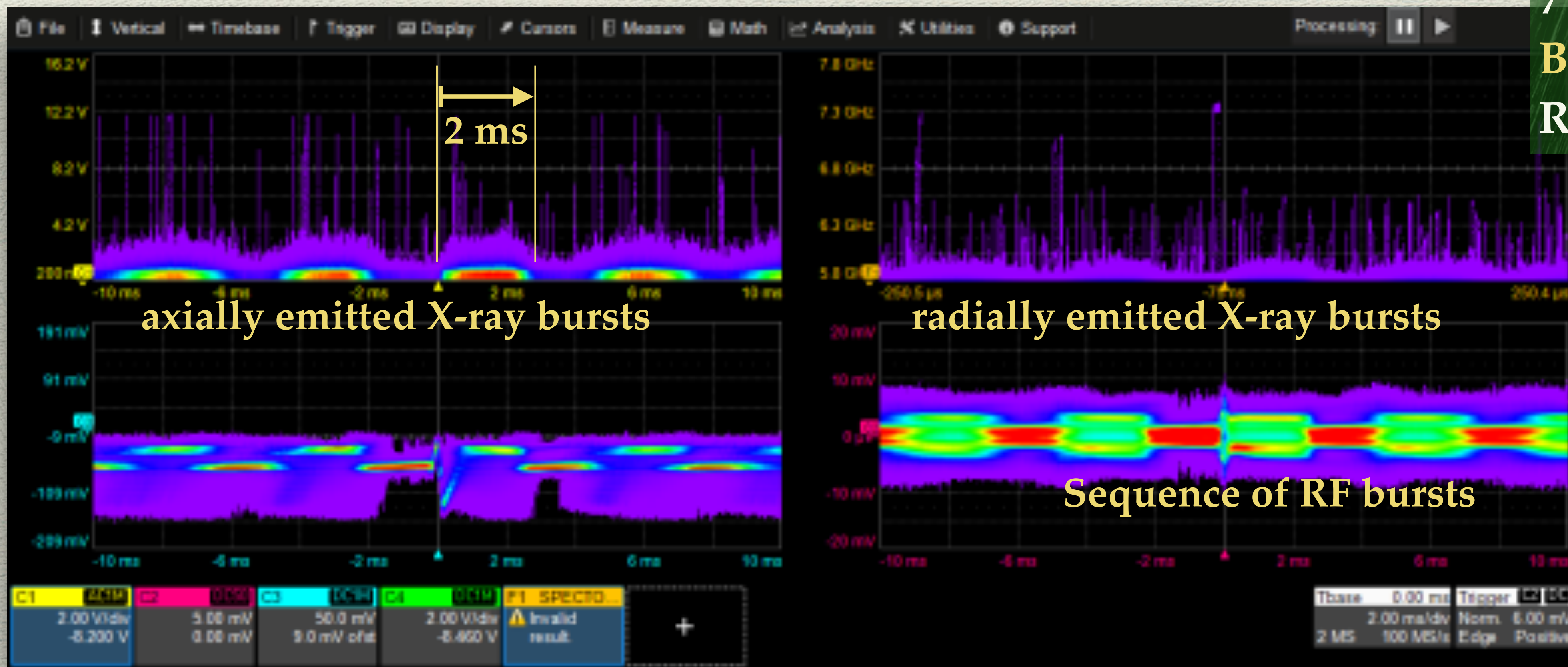


Probing turbulent plasma regimes (CYCLOTRON MASER INST.) in a Time-Resolved way

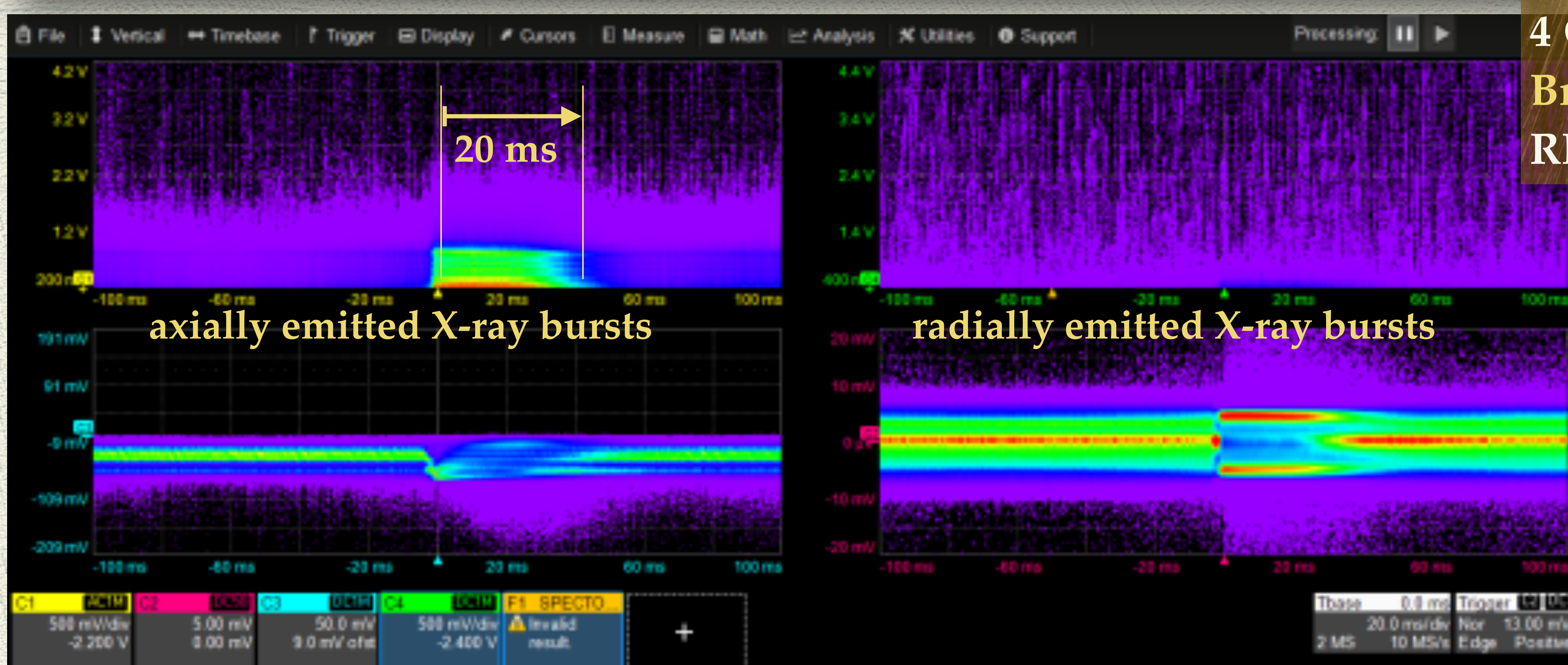


Radio-Bursts

INSTABILITY ONSET DEPENDS FROM THE AXIAL TRAP'S SCALE-LENGTH ONLY!! (*L parameter*)



7 GHz
Bmin/Becr=0.8
RF power= 250 W



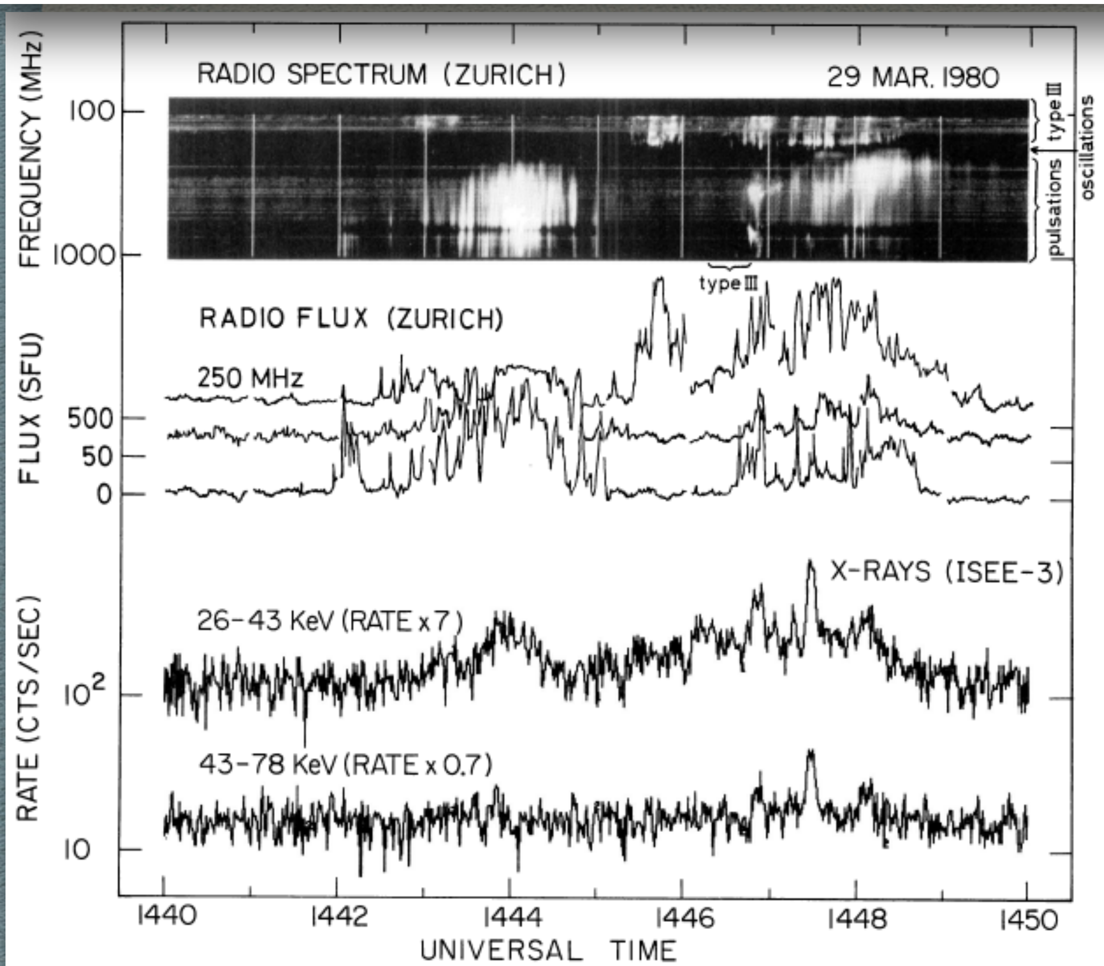
4 GHz
Bmin/Becr=0.95
RF power= 250 W

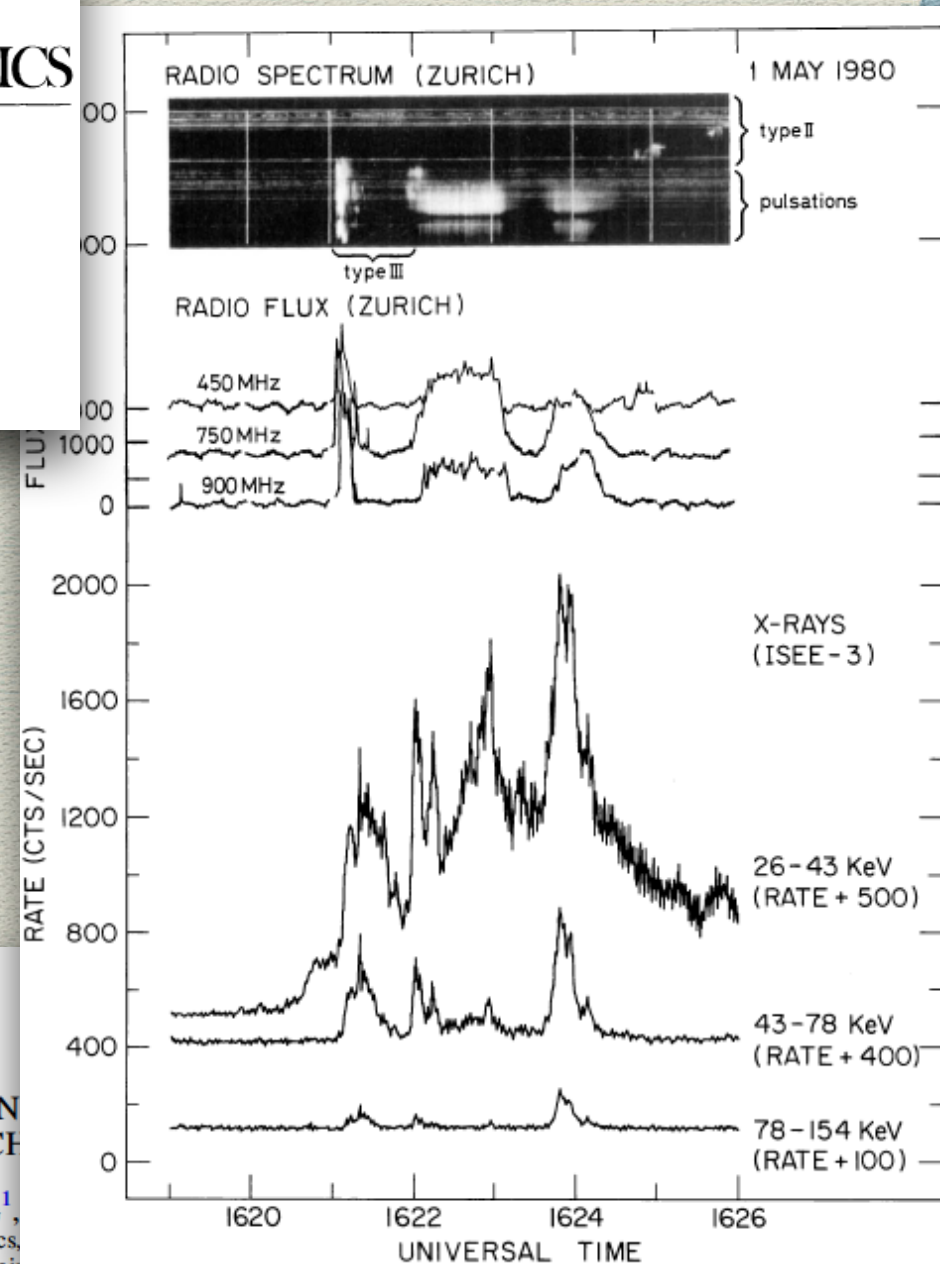
Astron. Astrophys. 229, 206–215 (1990)

ASTRONOMY AND ASTROPHYSICS

Correlation of solar radio pulsations with hard X-ray emission

M. J. Aschwanden ⋆, A. O. Benz [1], and S. R. Kane [2]





TROPHYSICAL JOURNAL, 822:58 (8pp), 2016 May 10

CYCLOTRON MASER EMISSION
PITCH

G. Q. ZHAO[1], H. Q. FENG[1],
[1] Institute of Space Physics,
[2] Purple Mountai
[3] Xinjiang Astronomical Observatory, CAS, Urumqi 830011, China
Received 2016 January 25; accepted 2016 March 6; published 2016 May 5

A&A 370, 1000–1003 (2001)
DOI: 10.1051/0004-6361:20010290

Astronomy & Astrophysics

Coherent cyclotron maser radiation from UV Ceti

R. Bingham[1,2,3], R. A. Cairns[3], and B. J. Kellett[1]

Comparison with self-consistent simulations

Solving the ***time-dependent Vlasov equation****, including single particle collisions*

$$\frac{\partial f_\alpha}{\partial t} + \vec{v}\cdot\vec{\nabla} f_\alpha + \frac{q_\alpha}{m_\alpha}\left(\vec{E} + \frac{\vec{v}\times\vec{B}}{c}\right)\cdot\vec{\nabla}_{\vec{v}} f_\alpha = 0$$

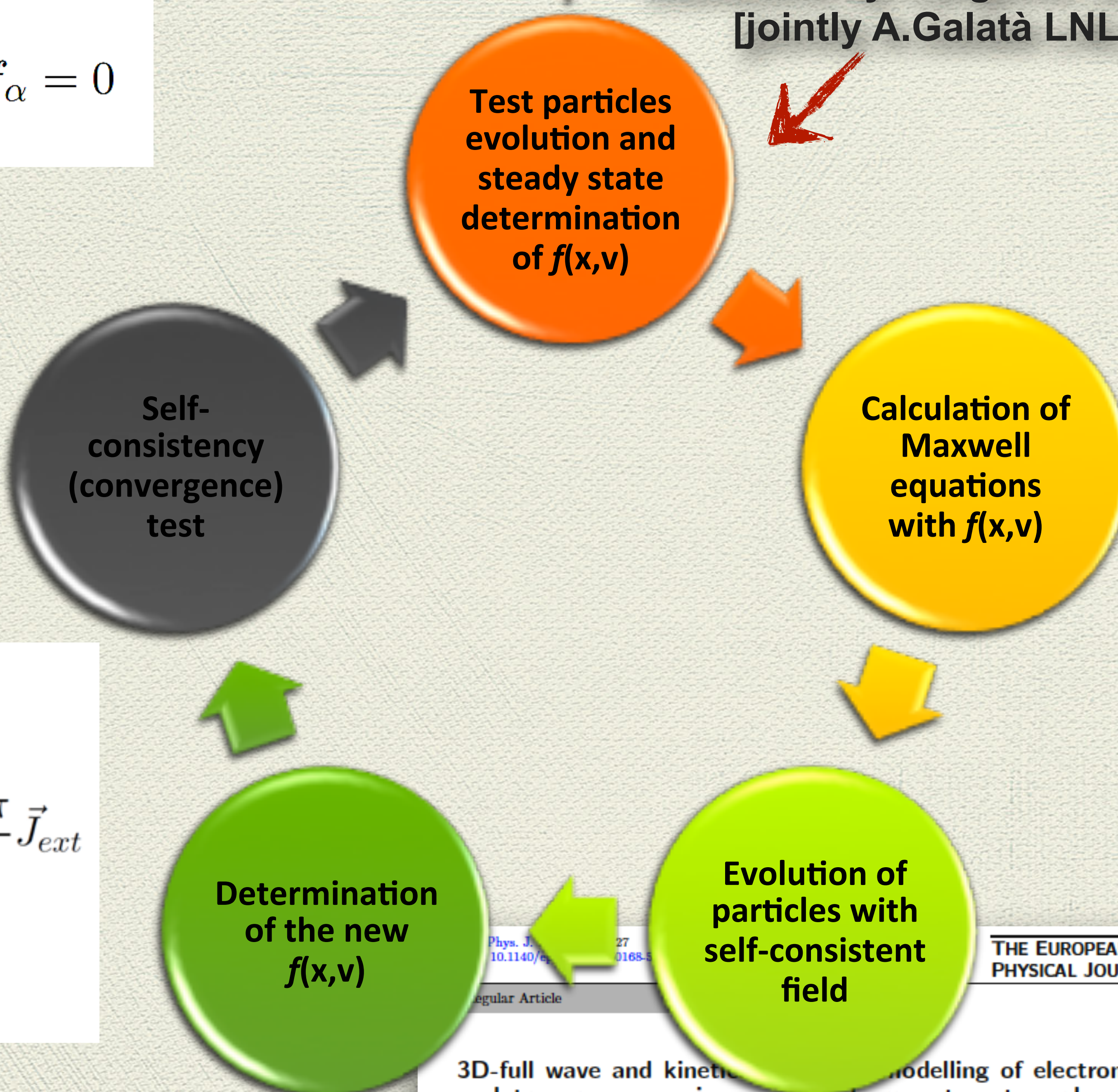
$$\frac{d\vec{v}}{dt} = \frac{q}{m_0\gamma}\left[\vec{E} + \vec{v}\times B - \frac{\vec{v}\cdot\vec{E}}{c^2}\vec{v}\right]$$

Collisions by Langevin method [jointly A.Galatà LNL]

Step-by-step current

Step-by-step plasma density

$$\begin{aligned}
\vec{\nabla}\cdot\vec{E} &= 4\pi\sum_\alpha \overline{n}_\alpha q_\alpha \boxed{\int f_\alpha d\vec{v}} + 4\pi\rho_{ext} \\
\vec{\nabla}\times\vec{B} &= \frac{1}{c}\frac{\partial\vec{E}}{\partial t} + \frac{4\pi}{c}\sum_\alpha \overline{n}_\alpha q_\alpha \boxed{\int \vec{v} f_\alpha d\vec{v}} + \frac{4\pi}{c}\vec{J}_{ext} \\
\vec{\nabla}\times\vec{E} &= -\frac{1}{c}\frac{\partial\vec{B}}{\partial t}
\end{aligned}$$



THE EUROPEAN PHYSICAL JOURNAL D

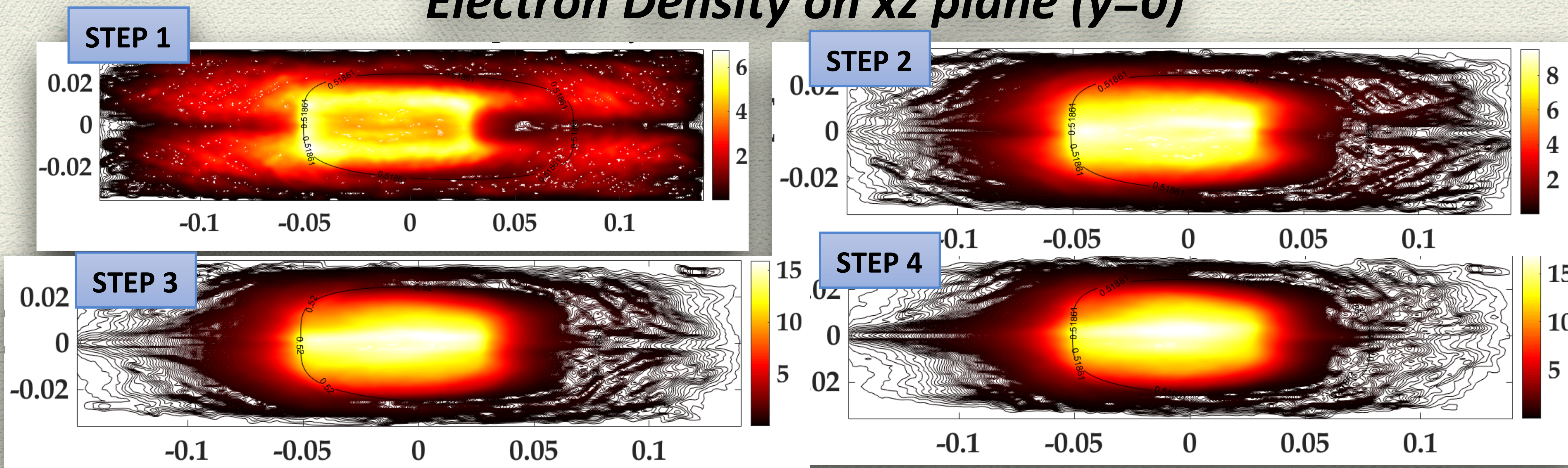
Regular Article

3D-full wave and kinetic ... modelling of electron cyclotron resonance ion sources plasma: steps towards self-consistency

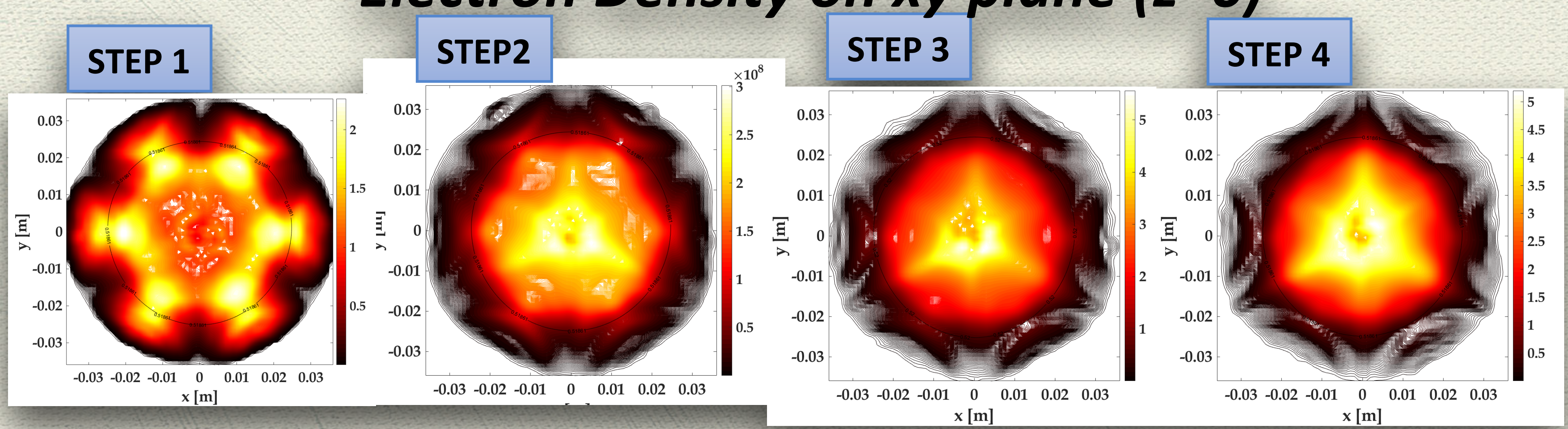
David Mascali[1], Giuseppe Torrisi[1,2,a], Lorenzo Neri[1], Gino Sorbello[1,3], Giuseppe Castro[1], Luigi Celona[1], and Santo Gammino[1]

Road Towards Self Consistency…
exit from the loop

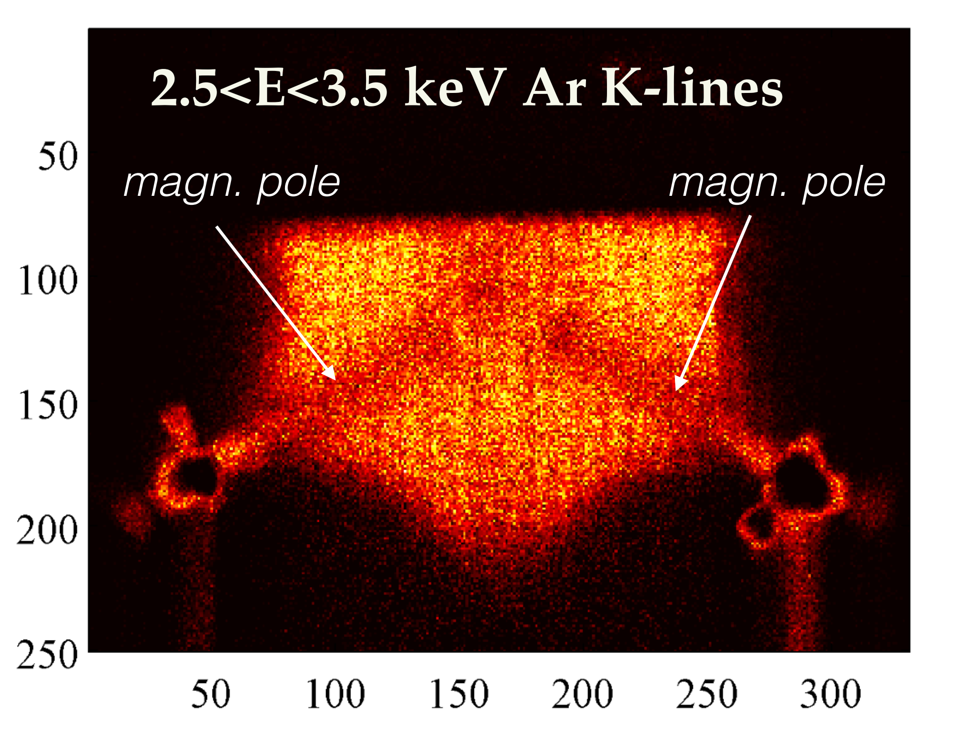
Electron Density on xz plane (y=0)



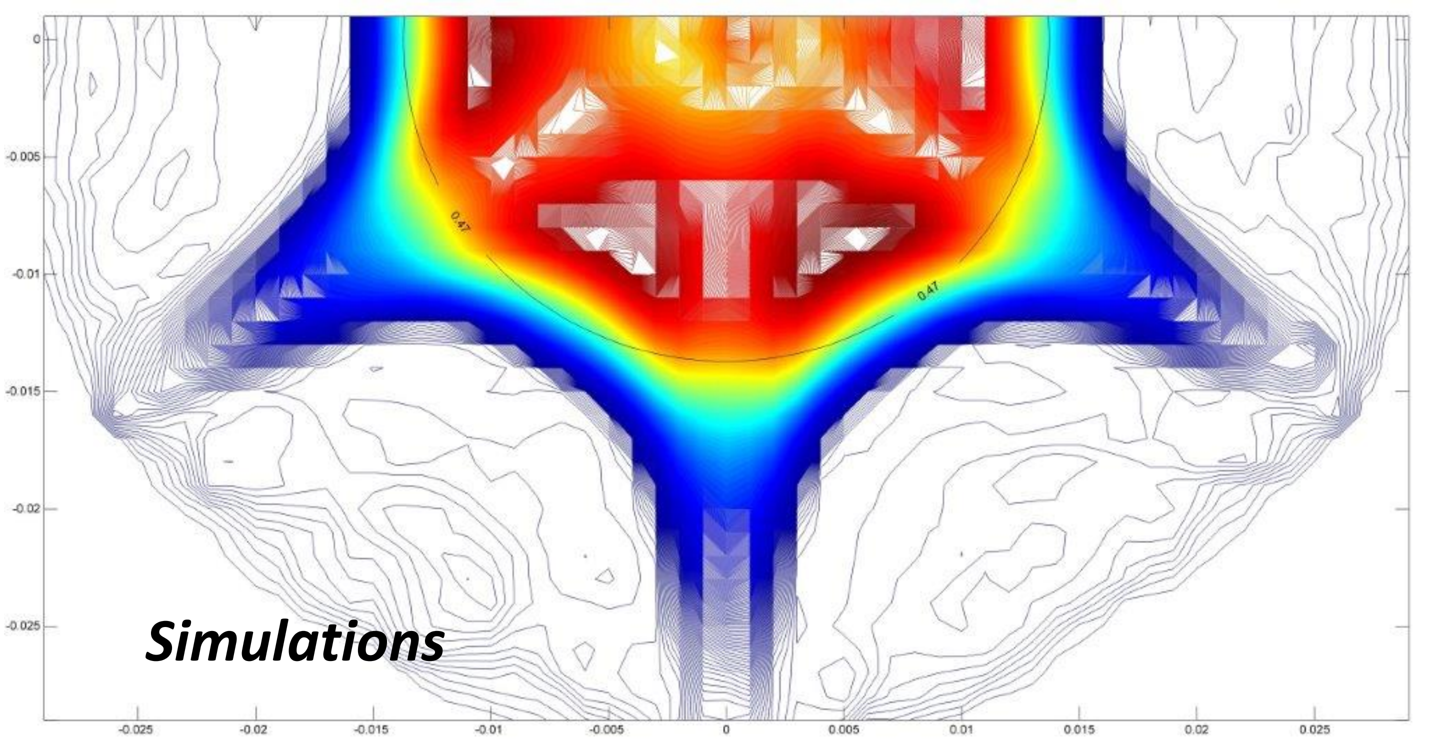
Electron Density on xy plane (z=0)

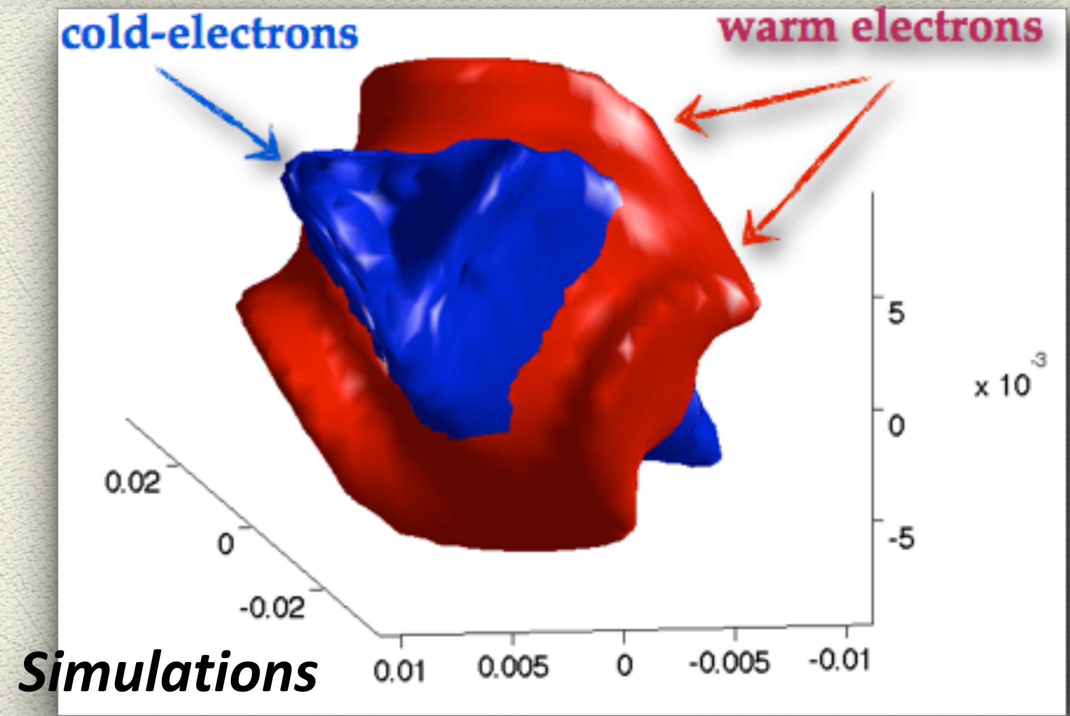


X-ray imaging and 3D plasma modelling



X-ray fluorescence from Ar ions in the plasma





3D self-consistent simulations very well reproduce energy content distribution of the plasma, which in turn fits with experimental detected displacement of Argon ions

Injection of rare isotopes in the magnetoplasma

Short lifetime
(e.g. ^{7}Be, ^{13}N, ^{15}O)

Charge Breeding
(in-flight-in-plasma capture)

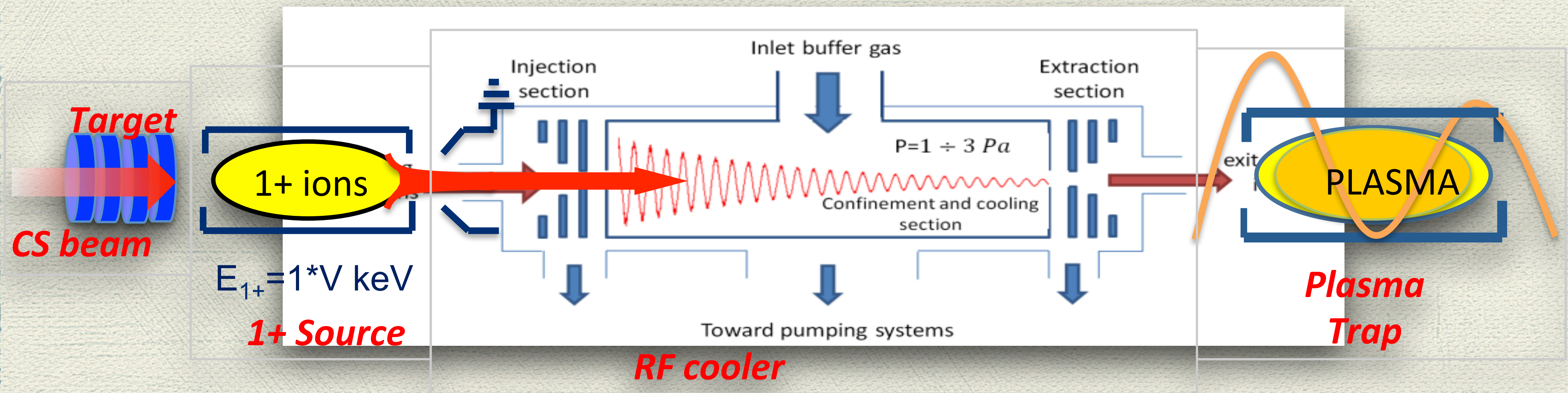
Long lifetime
(e.g. ^{187}Re, ^{176}Lu, ^{85}Kr)

Classical evaporation systems
(resistive/inductive ovens)

1. On-Line Measurements of n, T, CSD of the plasma
+
2. ^{7}Be handling and injection into the plasma trap

PANDORA feasibility study

Towards the PANDORA's TDR
On-line production of radionuclides at LNS with the upgraded Cyclotron



Other than the first physics case of ^{7}Be, other radionuclides to be produced on-line include:

- **^{8}B (for investigating the $\beta^{+}2\alpha$ decay – *solar neutrino problem*)**
- **CNO cycle, ^{13}N, ^{15}O and ^{17}F decaying β^{+}**

Targets of BN and/or C will be designed and irradiated by high intensity C, O and Ne beams

Charge Breeding modeling

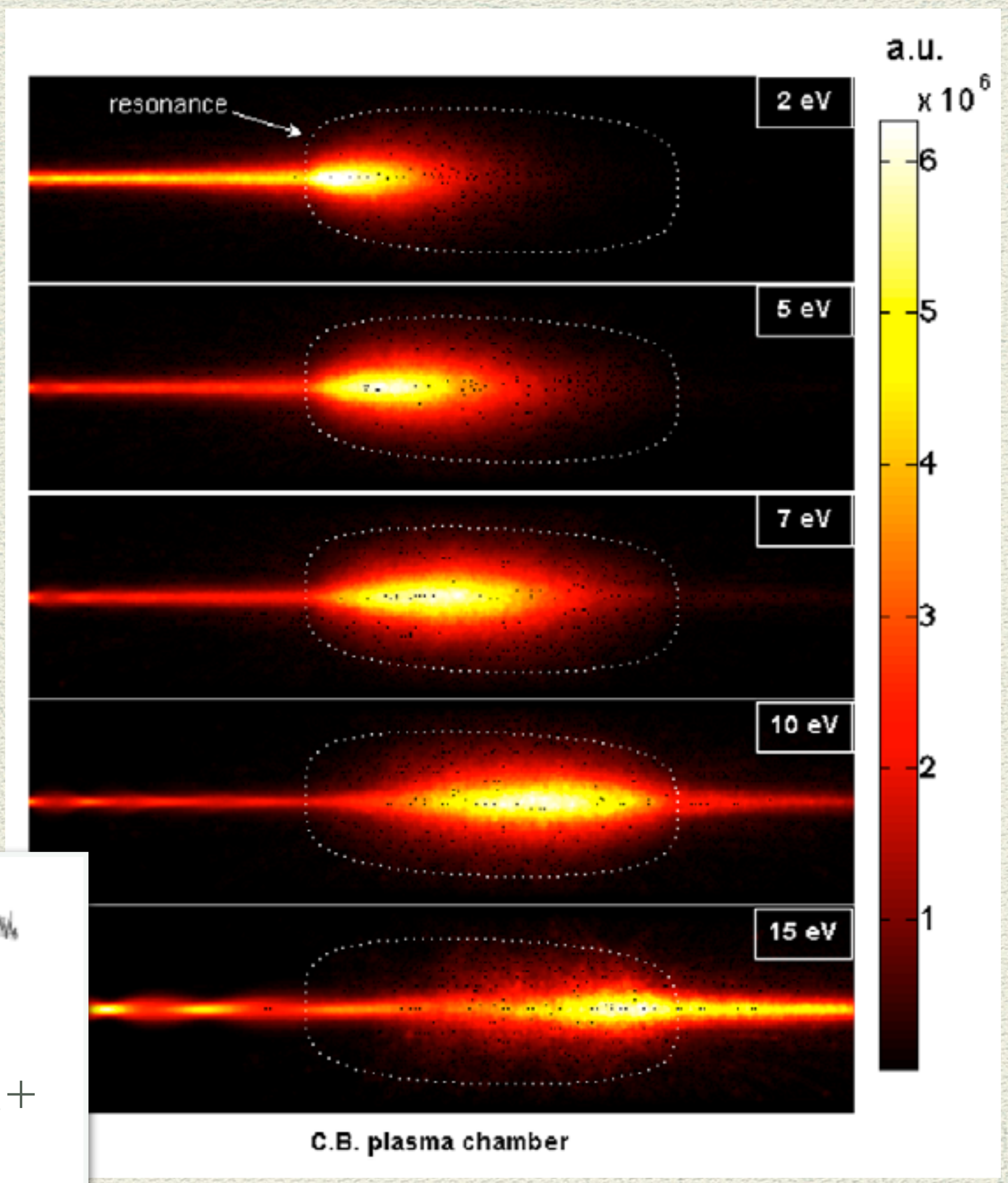
Ballistics studies

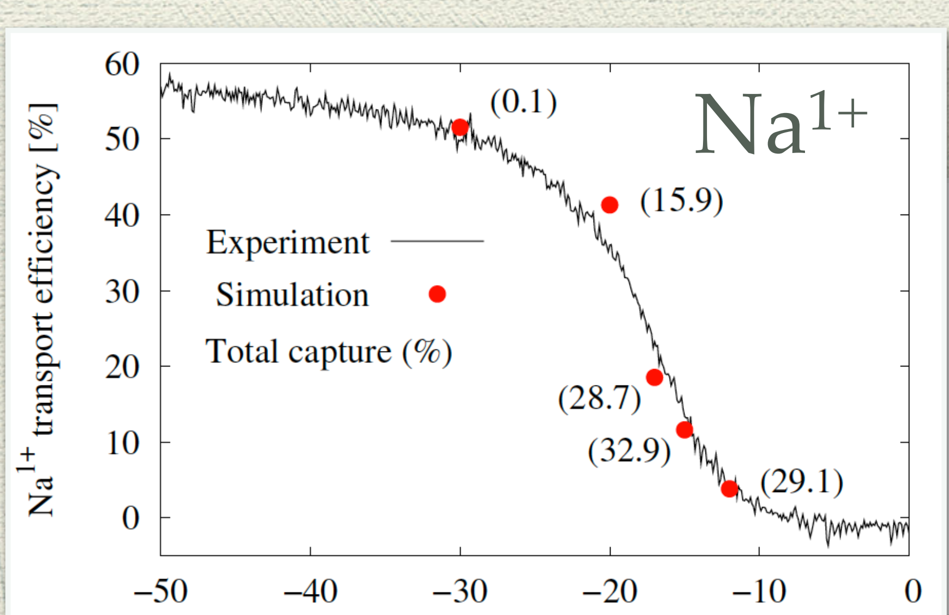
IOP Publishing — Plasma Sources Science and Technology
Plasma Sources Sci. Technol. 25 (2016) 045007 (17pp) — doi:10.1088/0963-0252/25/4/045007

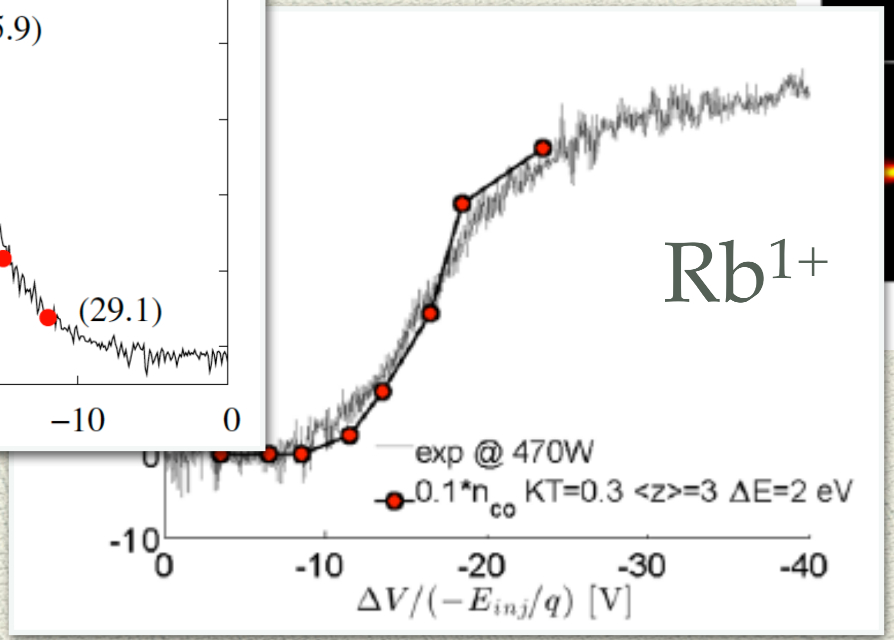
A new numerical description of the interaction of an ion beam with a magnetized plasma in an ECR-based charge breeding device

A Galatà[1], D Mascali[2], L Neri[2] and L Celona[2]

[1] INFN-Laboratori Nazionali di Legnaro, Legnaro, Padova, Italy
[2] INFN-Laboratori Nazionali del Sud, Catania, Italy







Agreement theor.-exp. for Na and Rb beams

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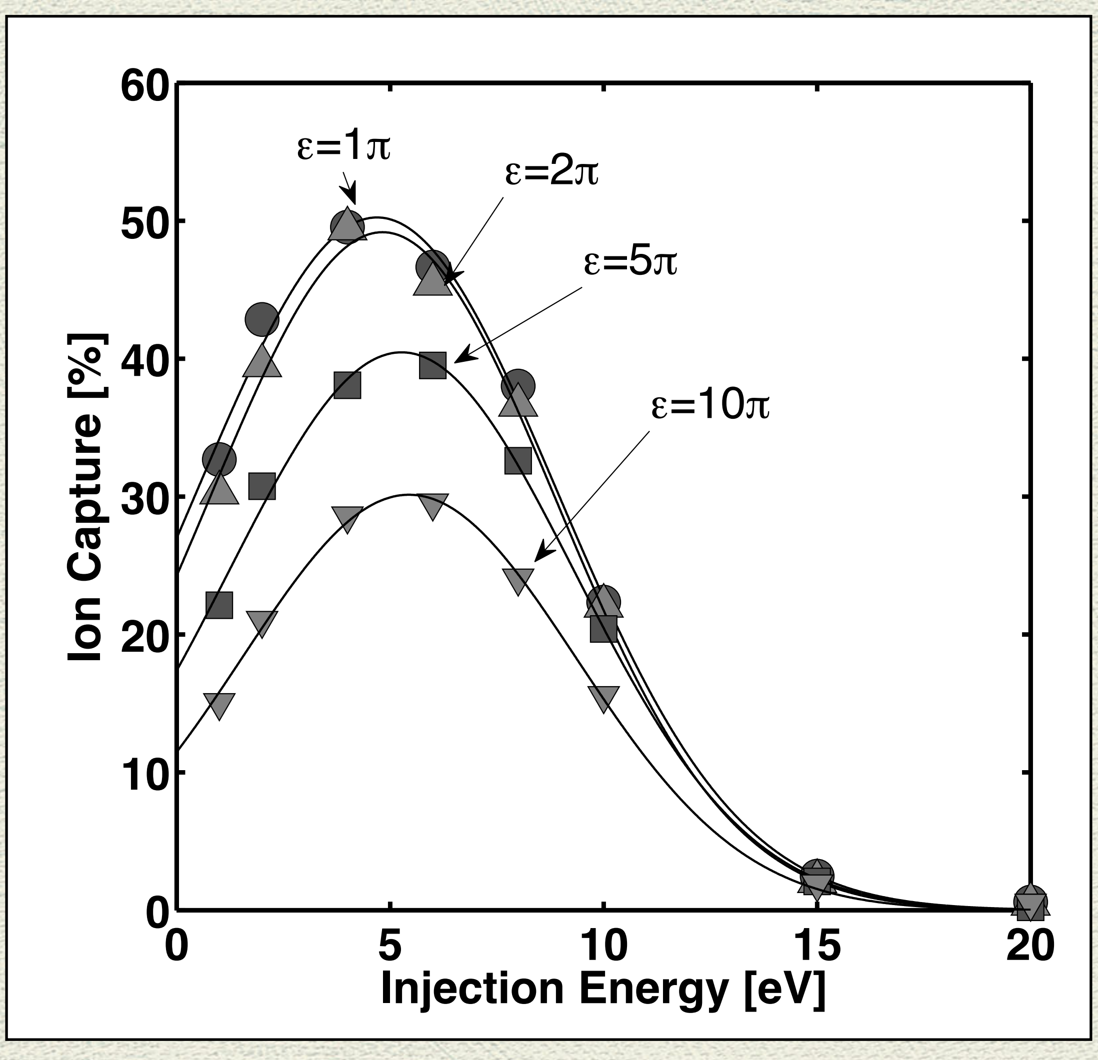
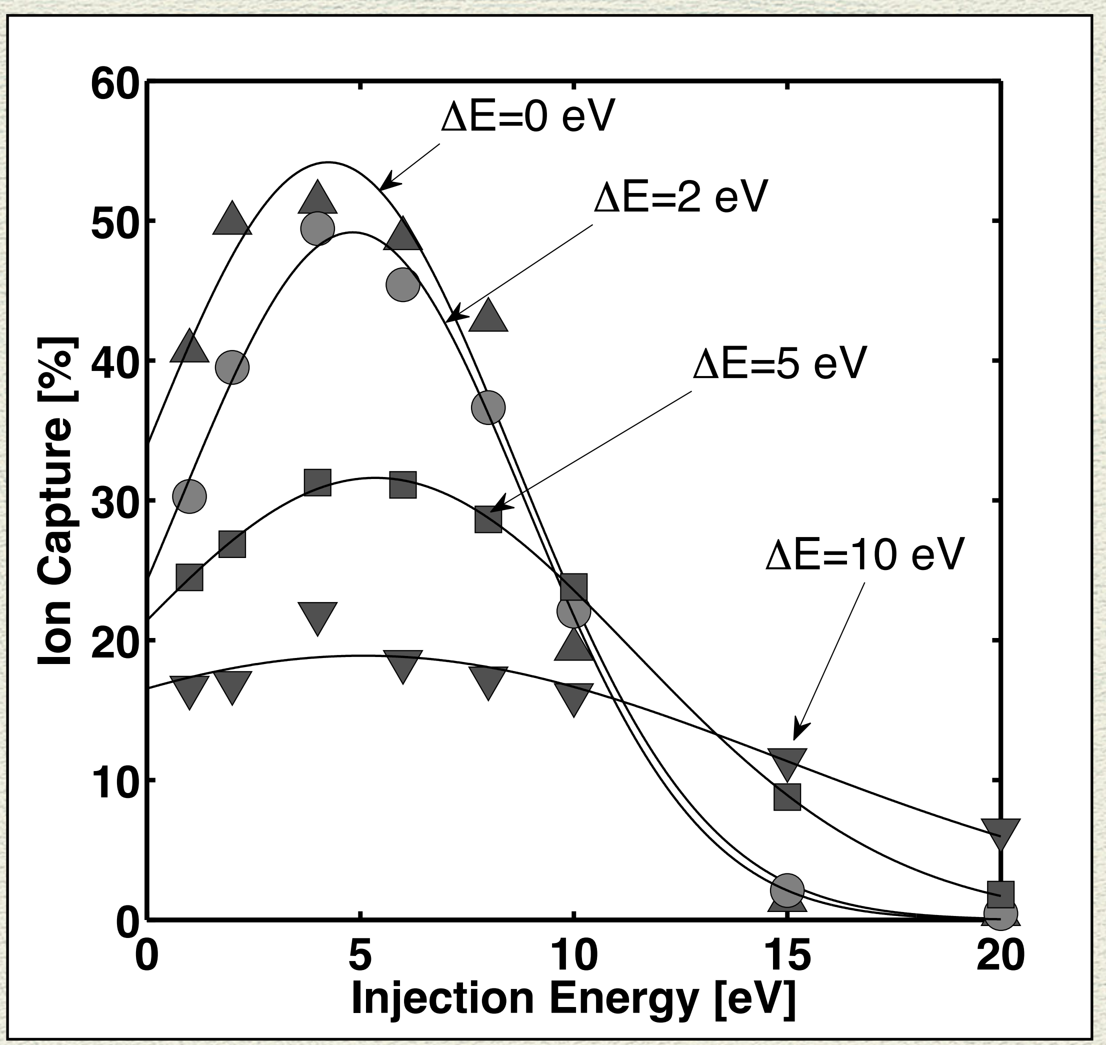
Charge Breeding modeling

Ballistics studies



Charge Breeding efficiency versus the emittance



Charge Breeding efficiency versus the energy spread

Numerical and Experimental results suggest RF cooler is needed!

SpectroPolarimetry for C.S.D. on-line measurements

Optical Emission Spectroscopy is already widely used worldwide to measure plasma density and temperature…

BUT…

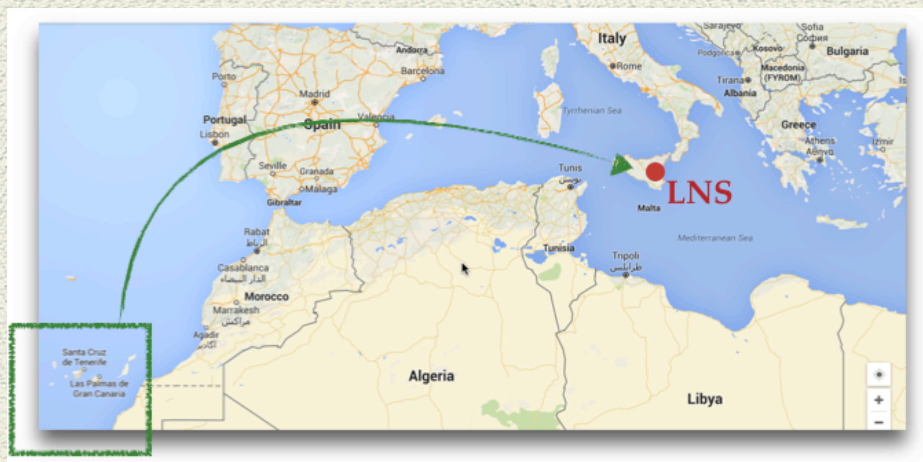
The effect of the magnetic field is rarely taken into account. It may affect in a relevant way line-ratios, etc.

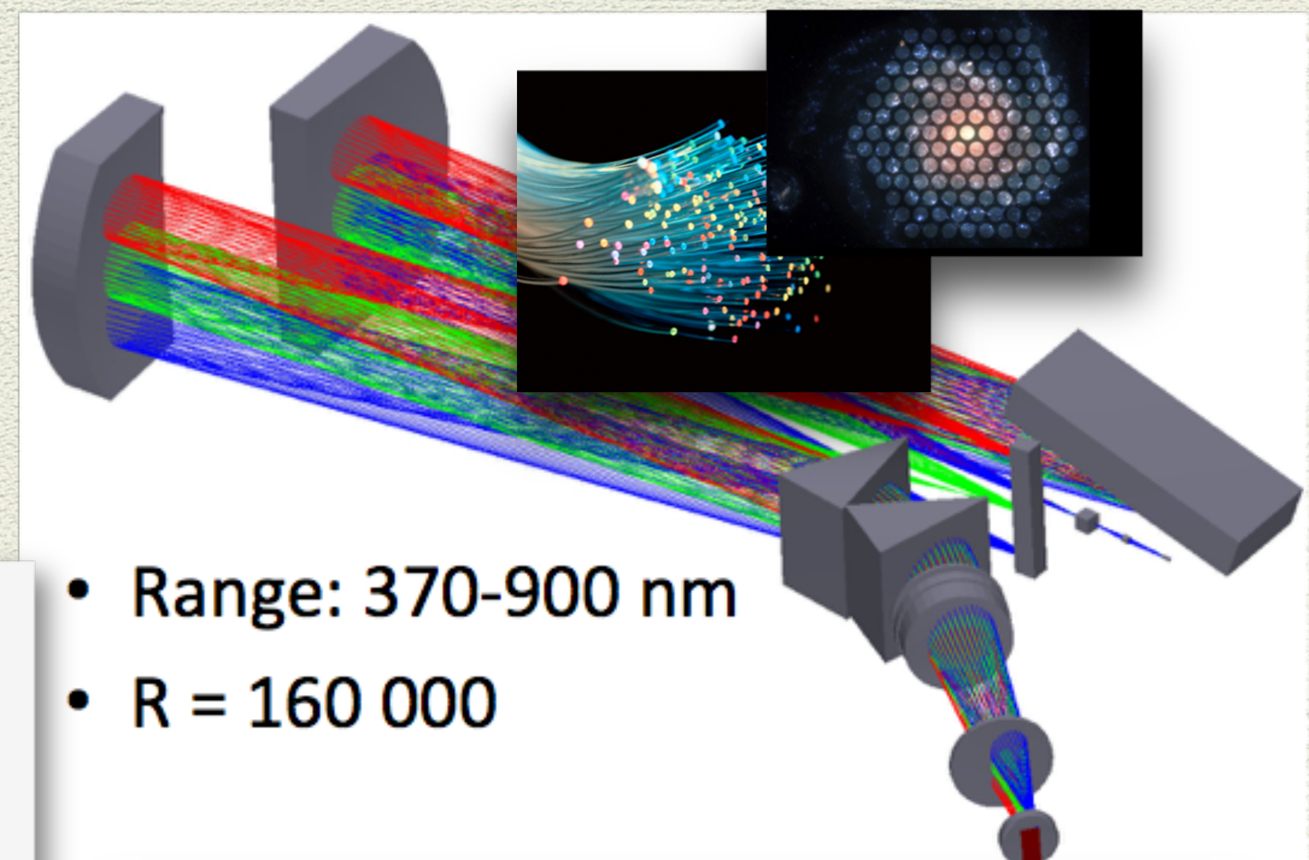
—> SPECTROPOLARIMETRY is needed!

Collaboration with Cambridge Univ. and University of Michigan started to integrate astrophysical databases to ECR plasmas

SpectroPolarimetry for C.S.D. on-line measure

Spettrografo Alta Risoluzione Galileo





- Range: 370-900 nm
- R = 160 000

PANDORA@Work

INFN-INAF *MoU*
in progress

the first *MoU* to
be signed by the two institutions

CSN III and V

INFN Istituto Nazionale di Fisica Nucleare

MEMORANDUM OF UNDERSTANDING

TRA

ISTITUTO NAZIONALE DI ASTROFISICA,
OSSERVATORIO ASTRONOMICO DI CATANIA

E

ISTITUTO NAZIONALE DI FISICA NUCLEARE,
LABORATORI NAZIONALI DEL SUD

RIGUARDANTE

Un'intensa sinergia su obiettivi comuni della ricerca scientifica al fine di incentivare le attività interdisciplinari basate sulla fisica dei plasmi ad alta densità e temperatura, di interesse per la produzione di fasci ionici, l'astrofisica nucleare e l'astrofisica osservativa, e segnatamente nel campo della propagazione a microonde in plasmi magnetizzati, della spettroscopia ottica/UV, della spettropolarimetria, e dell'analisi dell'emissione di raggi X.

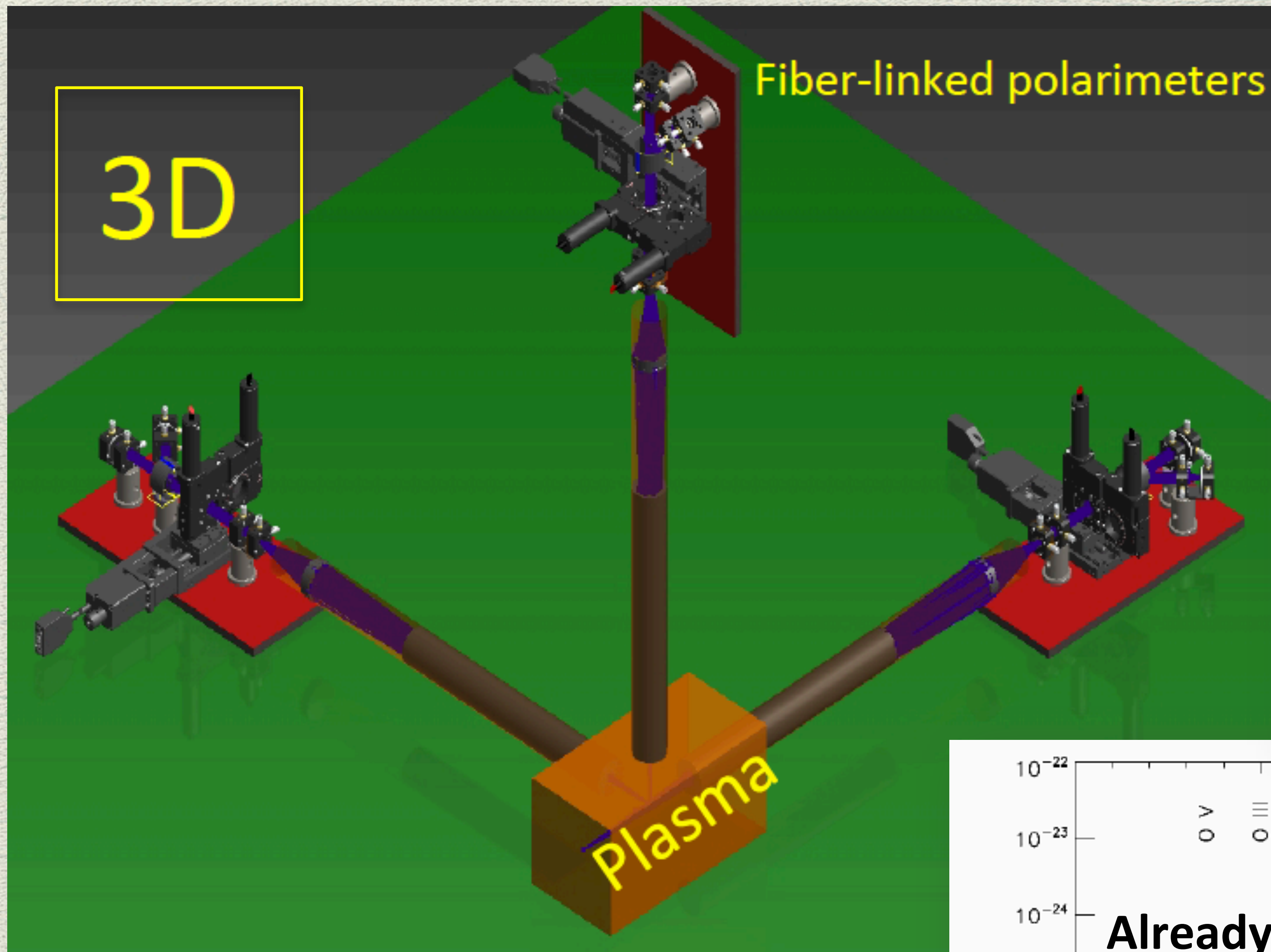
Starting a new synergy with Astronomy/Astrophysics!!!

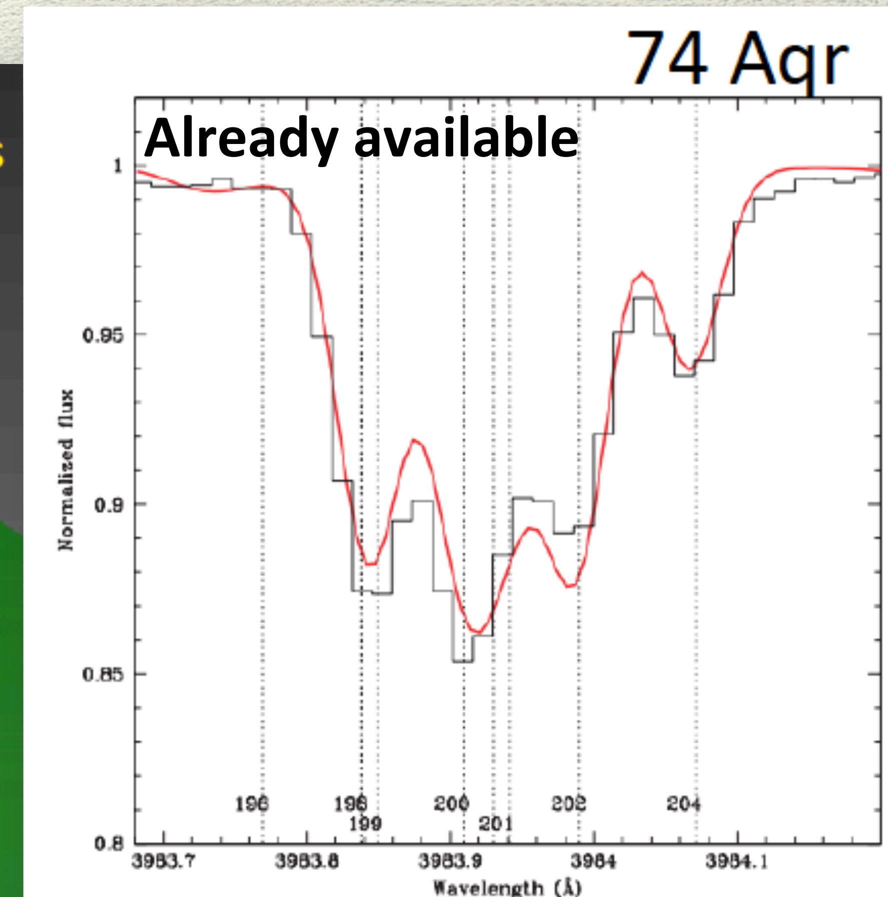
SARG has been transfered to LNS from T.N.G. in La Palma, Canary Islands

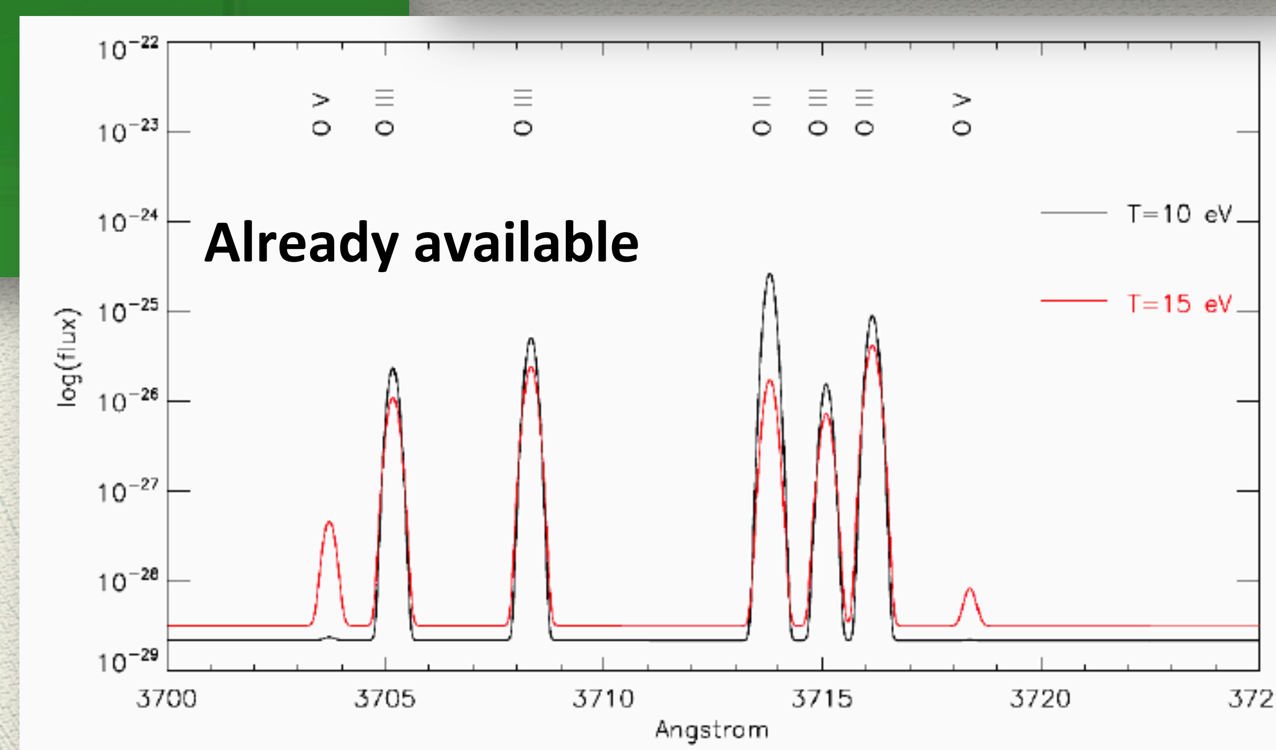
SARG@TNG, Canary Islands, has been one of the most powerful spectropolarimetry for the observation of magnetized stars' atmospheres

SARG@LNS, February 2018 –> Now in the installation phase

SpectroPolarimetry for C.S.D. on-line measurements

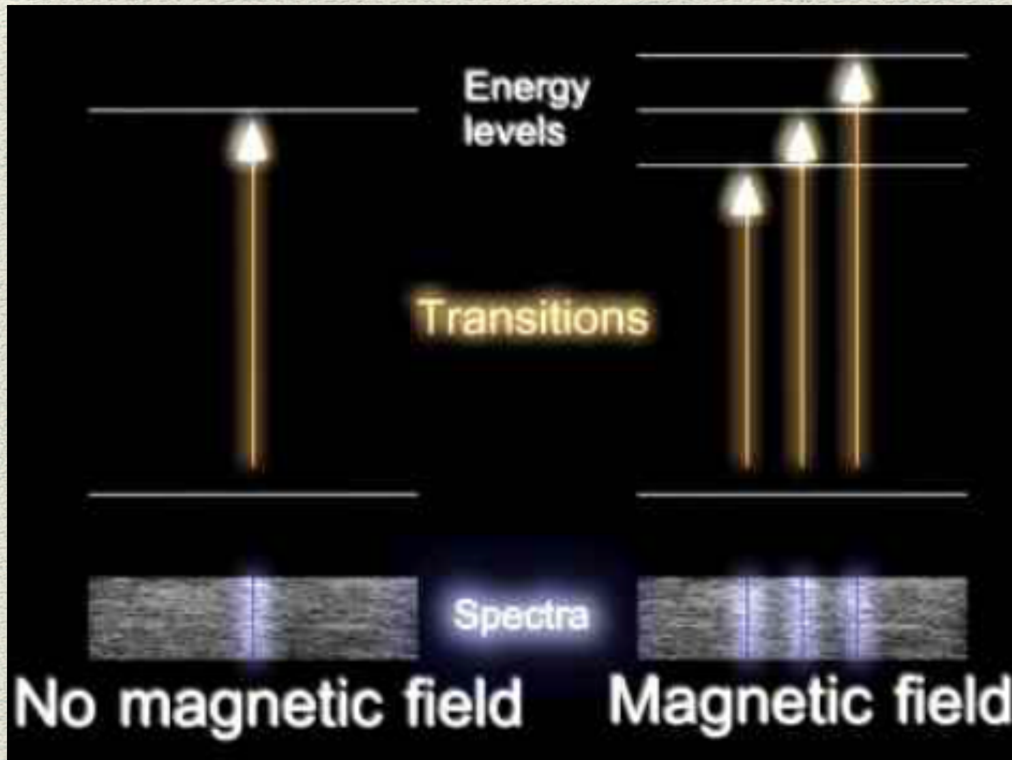




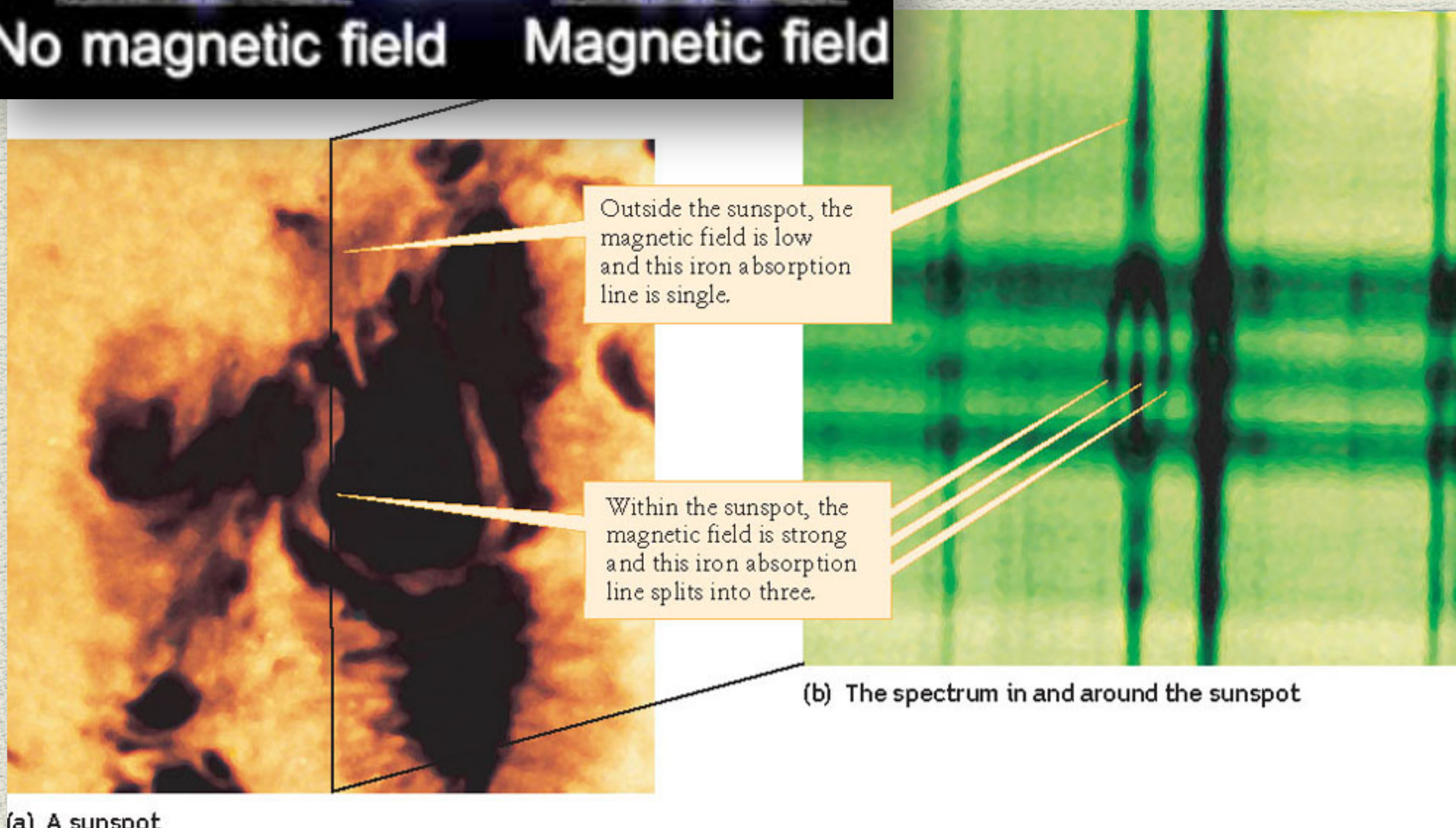


UPGRADE of SARG for allowing 3D plasma tomography is needed!!

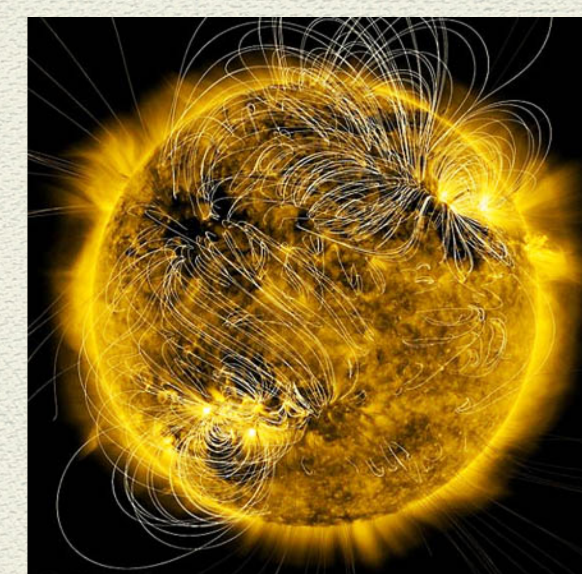
PANDORA's fall-out for Cosmic Magnetic Fields



Since George Ellery Hale (1908) we measure LS-coupling magnetic fields

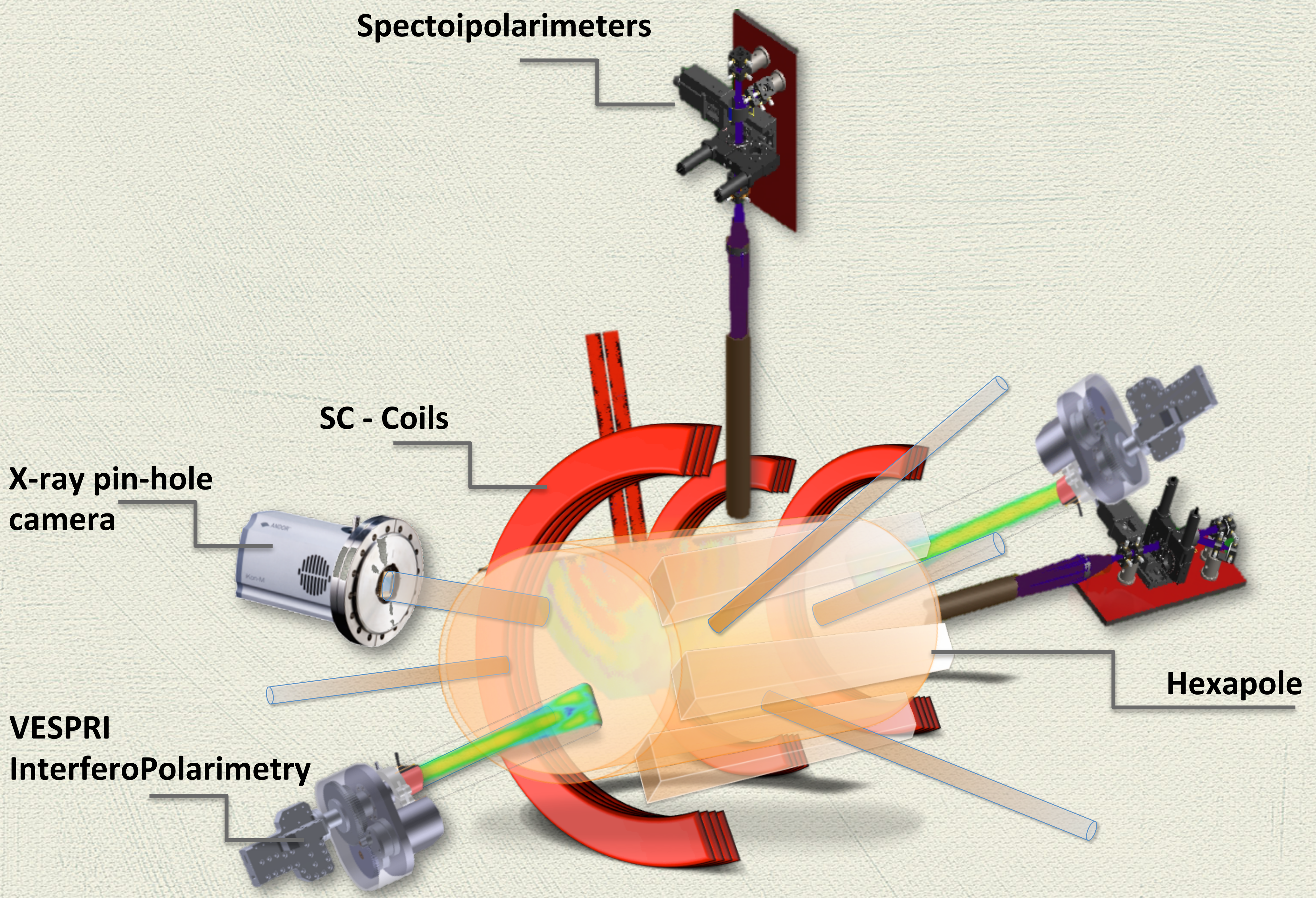


(a) A sunspot
(b) The spectrum in and around the sunspot



Building In-laboratory **DATABASE** of Landé factors

PANDORA Multi-Diagnostics approach



PANDORA's challenges: summary

DIAGNOSTICS: almost done for measuring plasma parameters in any spectral domain

BUT…

more space is needed! Let's think about new traps/ new plasma chambers

RARE ISOTOPES INJECTION: on line production + charge breeding

BUT…

for heavy elements (Cosmochronometers) new techniques are welcome!!

SUPPRESSION OF PLASMA TURBULENCE: experiments are ongoing

BUT…

more efforts are needed, and they are of relevance even for routine ECRIS operations.

Thank you very mych for your attention!!

NB:

PANDORA is a new experimental approach: comments, ideas, remarks, corrections... are warmly welcome!!