Mon-044

Development of laboratory experimental system to clarify solar wind charge exchange mechanism with TES microcalorimeter

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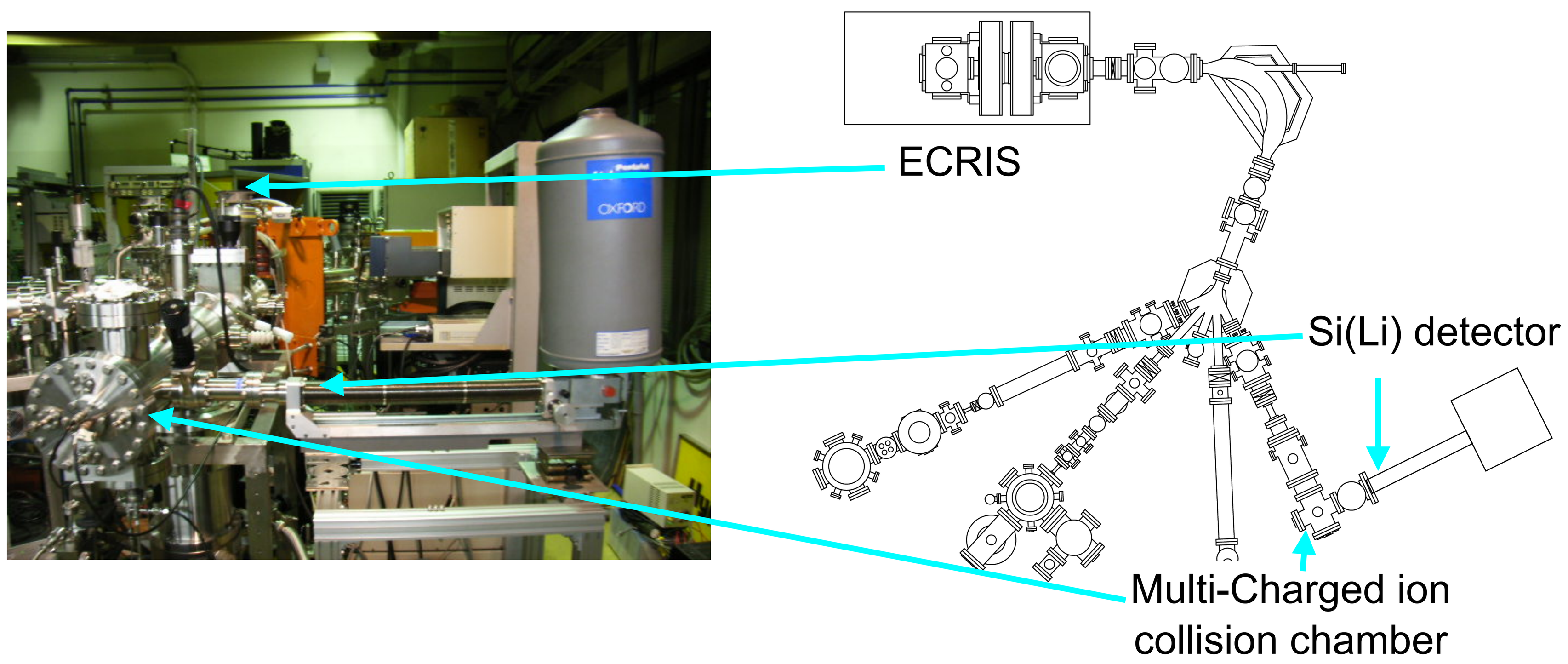
Abstract

Our experimental purpose is to measure Charge eXchange (CX) by O^{7+} - H, which is the most frequent reaction occurring in the earth neighborhood, in our laboratory system and to look into the population of emission lines and cross sections in detail.
We are developing a laboratory experimental system with transition edge sensor (TES) X-ray microcalorimeters cooled with a double-stage Adiabatic Demagnetization Refrigerator (dADR), in order to clarify the CX mechanism. This experiment is designed to measure the CX X-rays from an Electron Cyclotron Resonance Ion Source (ECRIS) that generates multi-charged ions.

1. ECRIS (Electron Cyclotron Resonance Ion Source) to produce Multi charged ion

Our group uses ECRIS as the ion source and the experimental setup is shown below.
- Multi-charged ions produced by ECRIS are sorted by an analyzing magnet with the ion charge in the middle of the beam line and are sent to the collision chamber.
- The ions collide with neutral gas in the collision chamber to cause the CX reaction, and the X-ray emission is measured by Si(Li) detector or TES microcalorimeter.



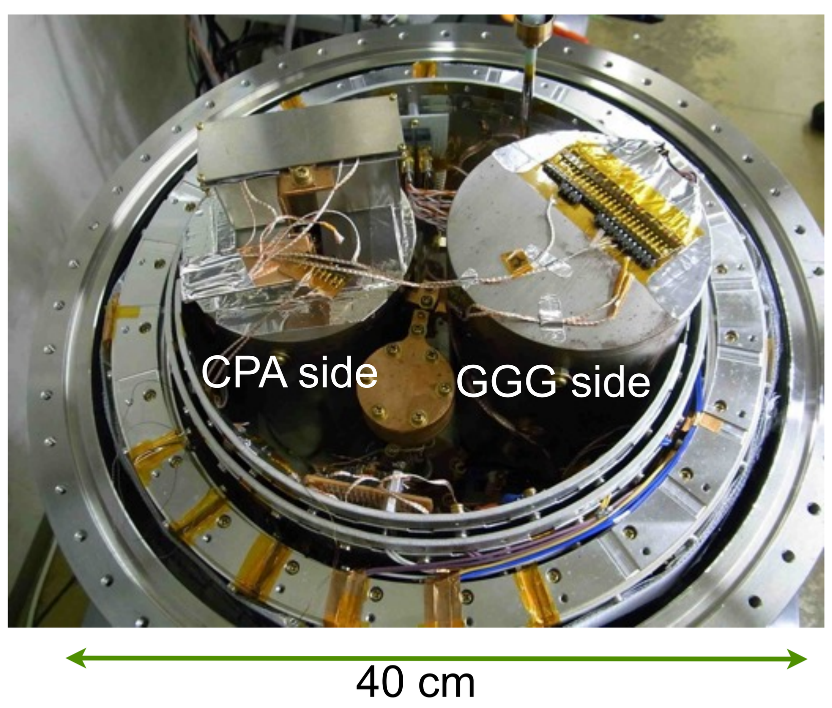
ECRIS principle

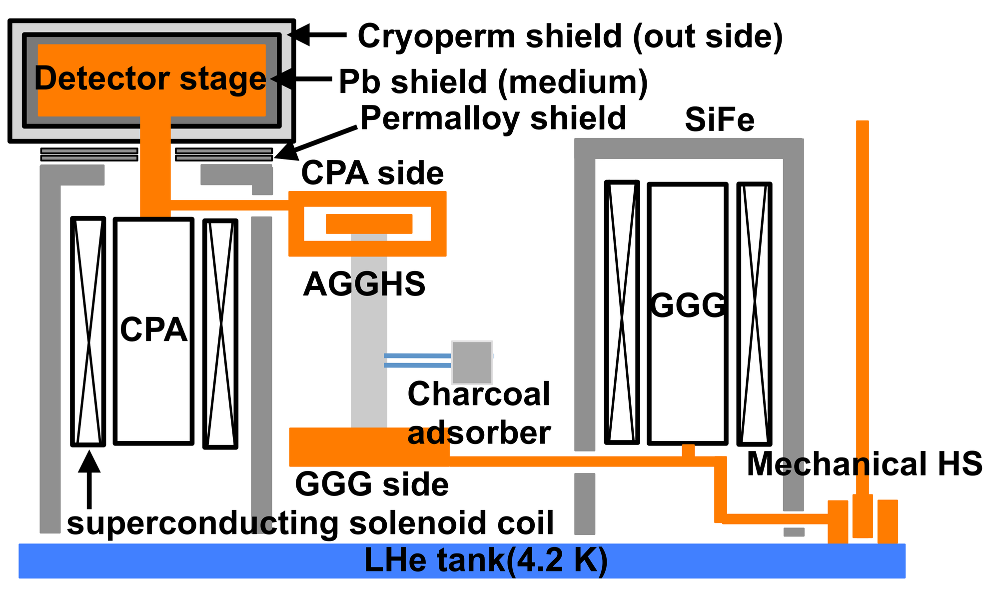
Highly charged ions are produced by successively stripping electrons from atoms and molecules by collisions of accelerated electrons. These incident electrons are in cyclotron motion under a magnetic field and are partly accelerated by a microwave irradiation.

Generable ion by ECRIS	up to fully stripped O and N ions
Collision energy	30 - 160 keV
Energy resolution of Si(Li) detector	160 eV for Mn Kα X-rays (5.9 keV)
Energy resolution of TES microcalorimeter	2.8 eV with our best record [1]

2. double-stage Adiabatic Demagnetization Refrigerator

We plan to use a double-stage Adiabatic Demagnetization Refrigerator (dADR) for cooling TES microcalorimeter. ADR utilizes entropy change of paramagnetic material.
The dADR has liquid He (LHe) tank and adopts vapor cooling system [2].





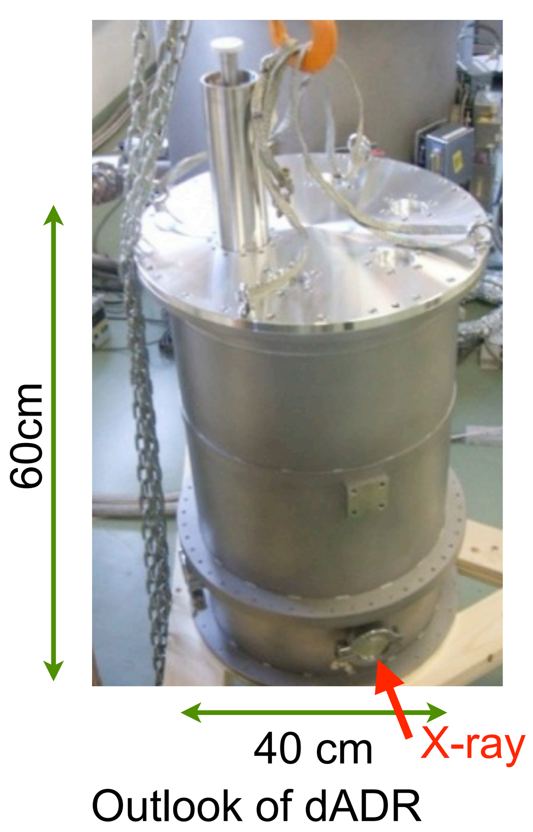
Our dADR system uses two heat switches:
- one is a mechanical heat switch between the LHe bath and the GGG stage,
- the other is an active gas-gap heat switch (AGGHS) between the GGG and the CPA stages

AGGHS principle

AGGHS is a switch that changes the thermal conductivity between the top and bottom parts by adsorbing He gas in charcoal [3].

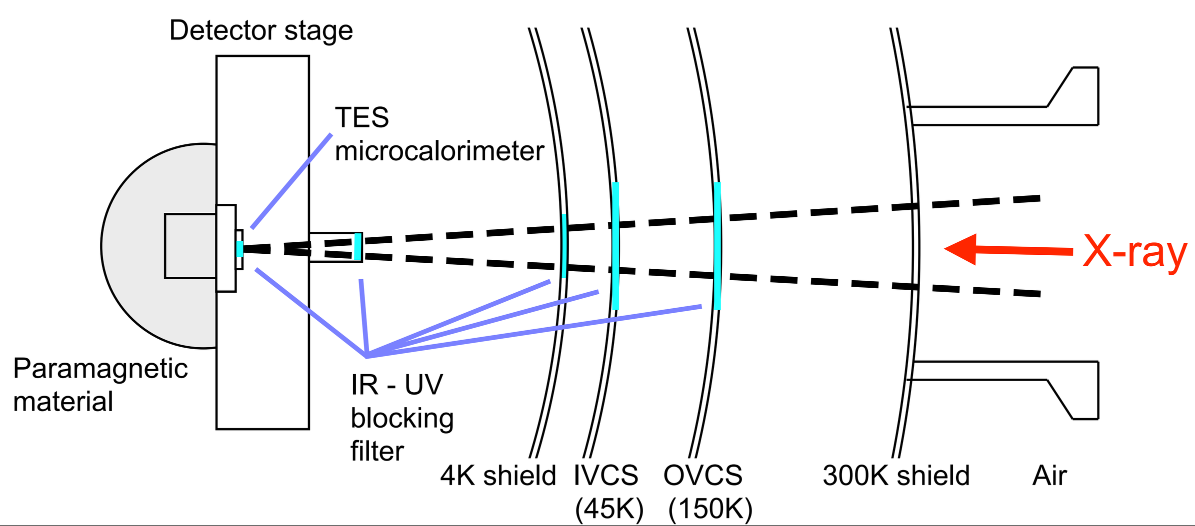
Paramagnetic material	GGG/CPA
Range	0.5 - 4.5K / 0.05 - 1K
Field	3.5T (8.0A) / 2.8T (8.5A)
Mass	600g / 90g

※ GGG : Gadolinium Galium Garnet
※ CPA : Chromium Potassium Alum



Outlook of dADR

Inside the dADR, there are four thermal shields;
4K shield, IVCS (45 K), OVCS (150 K) and 300 K shield.
There are five windows with IR - UV blocking filter, and transmission is expected to be 40%.
We expect count rates with TES measurement about 0.07 c s^{-1}.

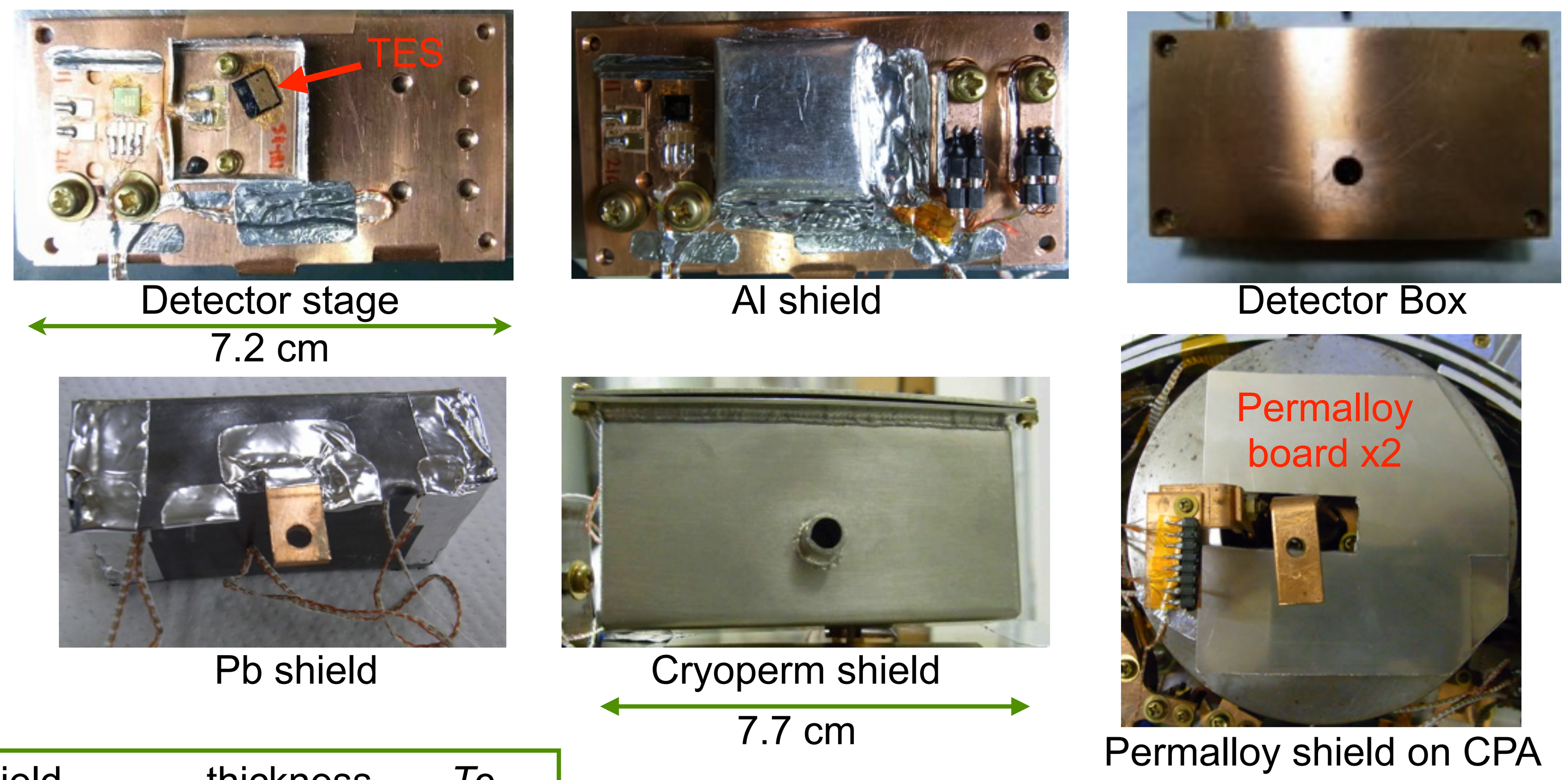


3. Magnetic shield for TES microcalorimeter

Magnetic field causes a significant change in the performance of TES microcalorimeters [4].

To avoid this, we employed a threefold magnet shield consisting of Al, Pb and Cryoperm with a high magnetic permeability around the TES device, and permalloy shield on the CPA.

TES	Ti / Au
size	350 x 350 um^2
transition temperature	147 mK
normal resistance	97 mΩ

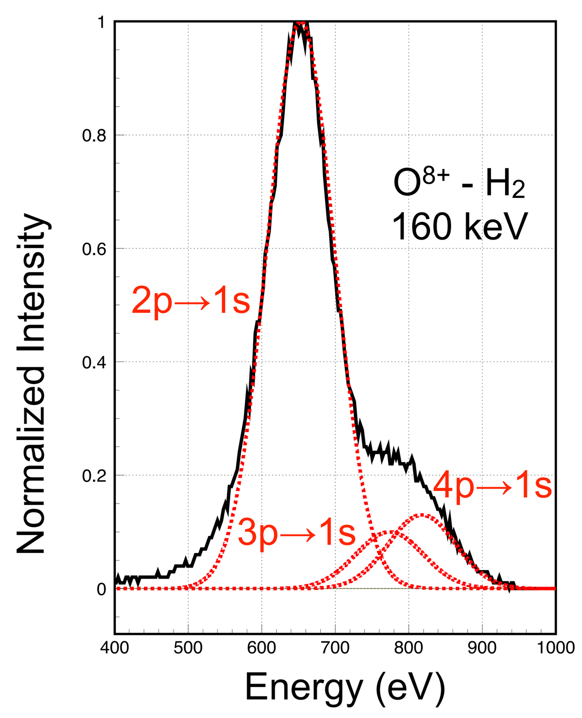


Sield	thickness	*Tc*
Al	0.5 mm	1.2 K
Pb	1 mm	7.2 K
Cryoperm	1 mm	-
Permalloy	0.5 mm x 2	-

※ *Tc* : transition temperature

Permalloy is suitable for magnetic shielding because permeability and saturation magnetic flux density are high, and remanent and the coersive force are small. At low temperature, the capability decreases, so that Cryoperm is used.

4. Results with Si(Li) detector



Result of window-less Si(Li) detector [5].
The spectrum show the 2p→1s line is the strongest, and suggests existence of the 3p→1s and 4p→1s lines.

transition	2p→1s	3p→1s	4p→1s
energy	653 eV	774 eV	817 eV

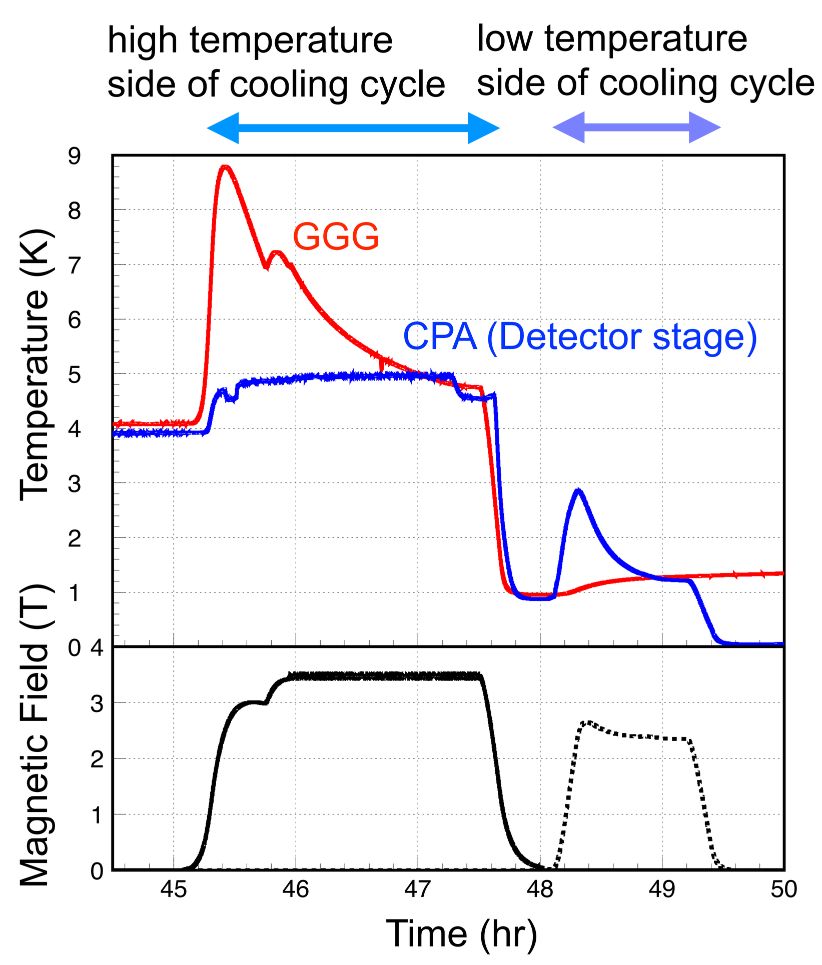
However, it was impossible to distinguish among the *np*→1s ($n \geq 3$) transitions of O^{7+} with the Si(Li) detector, and measurements with the TES microcalorimeter are necessary to resolve these emission lines.

5. Status and Prospects of dADR, TES, and ECRIS

We still have not performed the measurements of the CX X-rays with the TES microcalorimeter. There are several problems.

✻ TES

The biggest problem is that TES does not become superconductive when installed in the dADR even at 60 mK, much below *Tc* =147 mK measured in a dilution refrigerator. We will measure actual magnetic field with a Hall device and improve the magnetic shield.
As for the count rate, we introduce an X-ray capillary lens to increase the count rate with TES by a factor of several tens.



✻ dADR

Below is the current performance of the dADR. The hold time of the cooling cycle is short compared with our aim of 10 hour.
Typical cooling cycle is shown in right figure.

lowest temperature	45 mK
cycle time of cooling	5 hr
Hold time	2.6 hr

✻ ECRIS

ECRIS beamline also expects future improvements. We plan collisions with neutral H atoms (instead of H_2 molecule), installation of deceleration device to reduce the ion velocity down to the solar wind, and capability to measure forbidden lines by adding an ion trap device.

[1] Akamatsu et al, *LTD-13 AIP Conference Proc.* 1185, 191 (2009). [2] Shinozaki et al, *American Institute of Physics*, (2006). [3] Ishisakiet et al, *in these conferences*, (2011). [4] Ishisaki et al, *Low Temperature Detector LTD 13*, (2007). [5] Kanda et al, *Physica Scripta*, T144, 014025 (2011).