

太陽風多価イオンの電荷交換反応

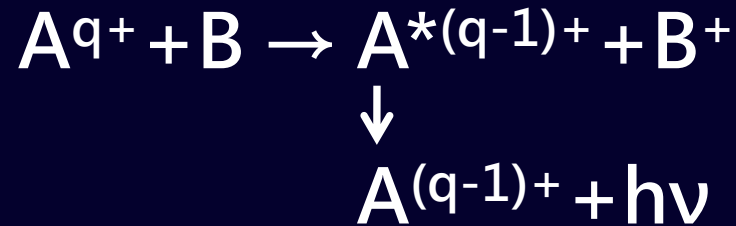
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石崎欣尚¹, 江副祐一郎¹, 大橋隆哉¹, 大橋隼人²,
篠崎慶亮³, 満田和久⁴, L. Liu⁵, J. Wang⁵, 田沼肇¹

¹首都大理工, ²電通大レーザー, ³ARD/JAXA, ⁴ISAS/JAXA, ⁵IAPCM/China



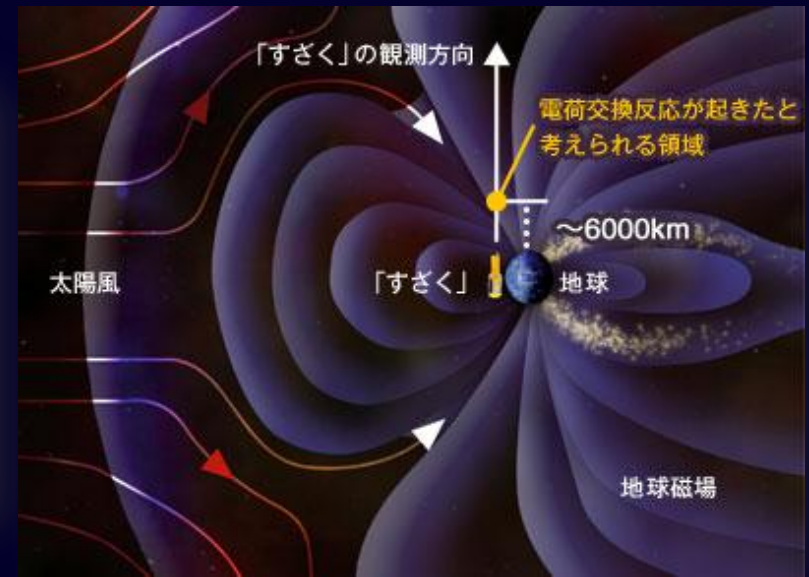
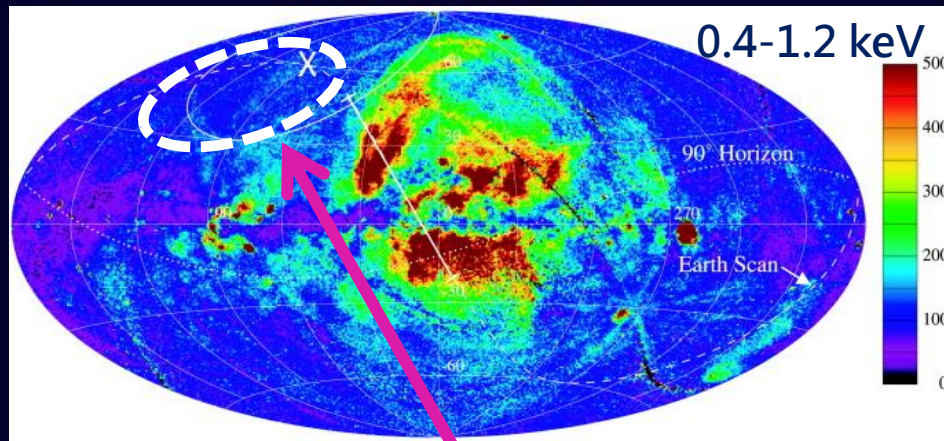
研究背景

太陽風と太陽系内中性物質との衝突による電荷交換反応
Solar Wind Charge Exchange (SWCX)



A = C, O, Ne...
 B = H, He

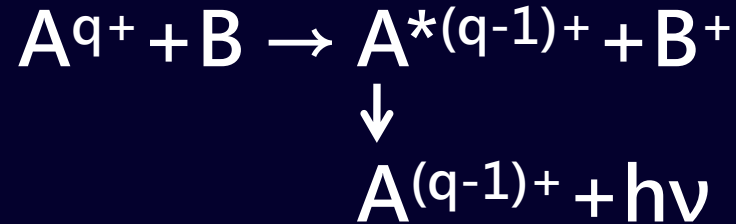
ROSAT衛星による軟X線全天マップ
 (Snowden et al., 1994)



短期間で時間変動する成分を観測

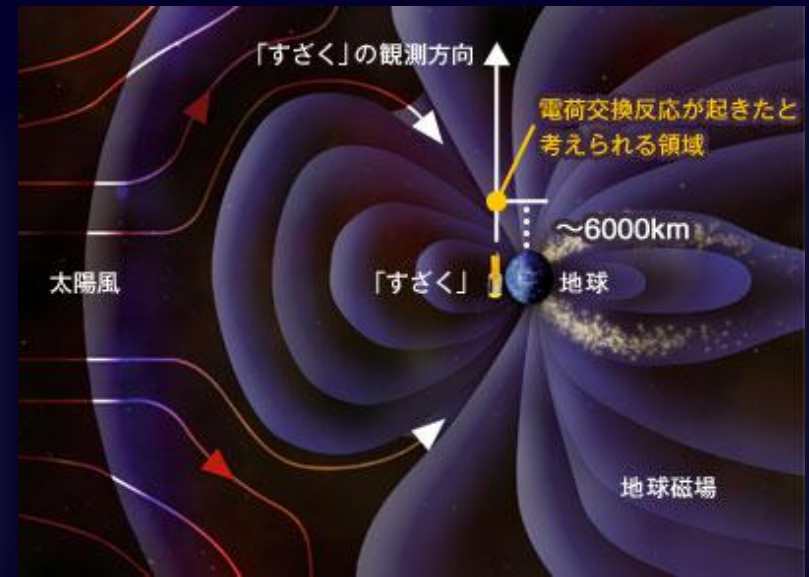
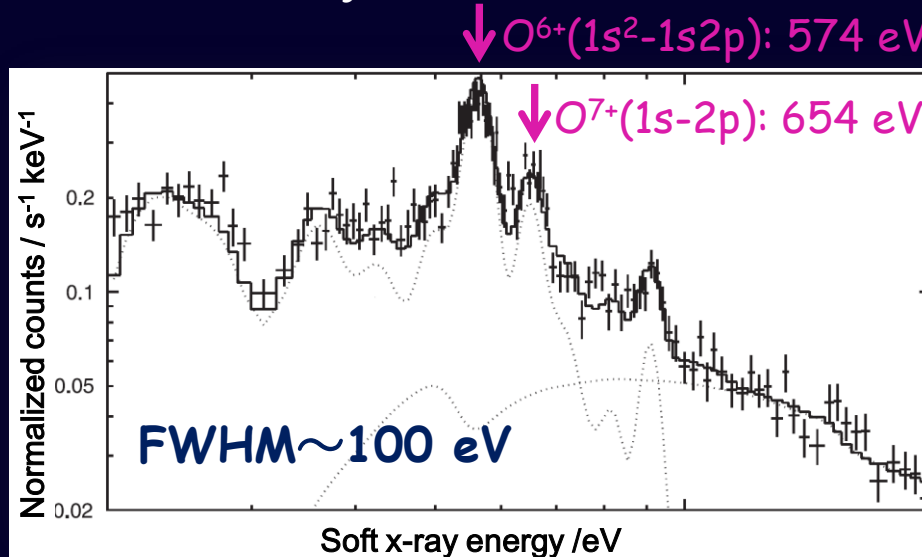
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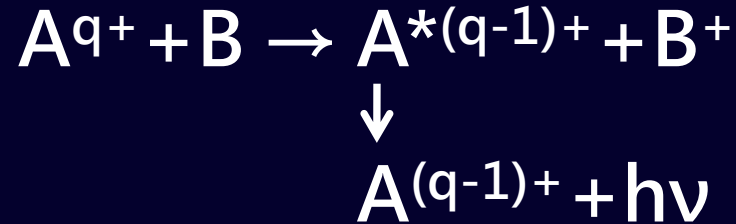
すざく衛星によるスペクトル
 (R. Fujimoto et al., 2007)



構造分離が不可 → 高分解能測定が必要
 発光断面積データの必要性

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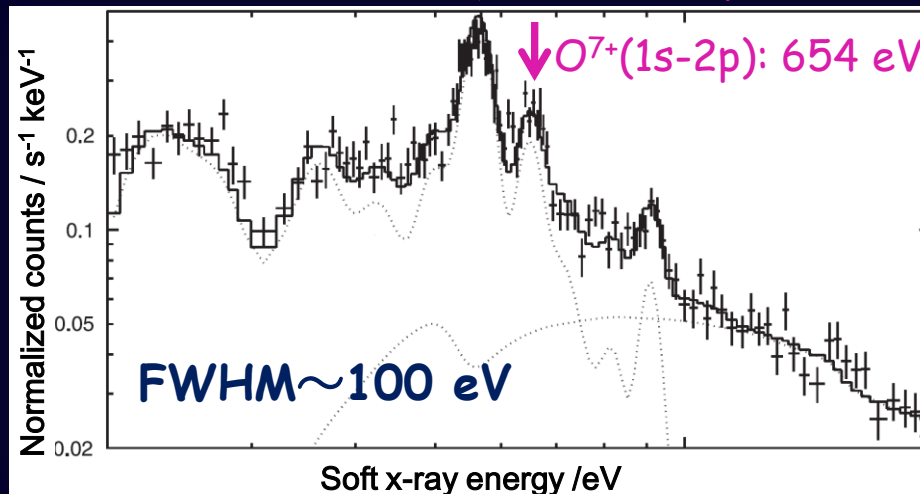


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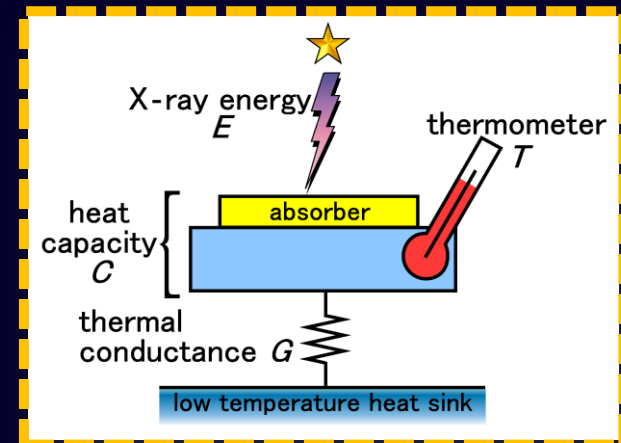
↓ $O^{6+}(1s^2-1s2p)$: 574 eV

↓ $O^{7+}(1s-2p)$: 654 eV



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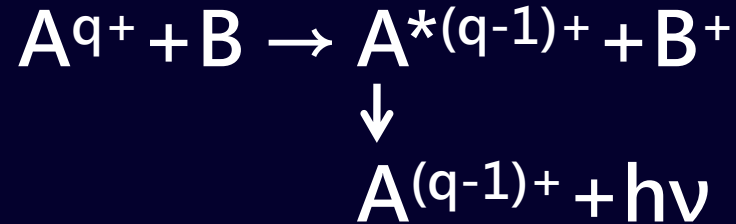
TESカロリメータ



FWHM < 10 eV

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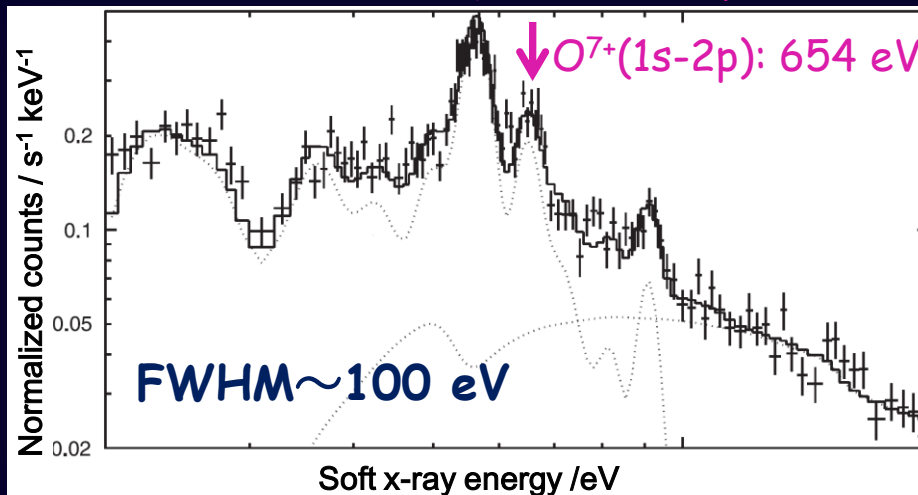


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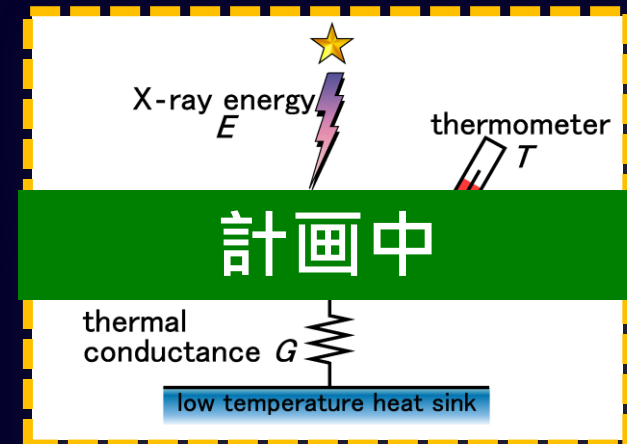
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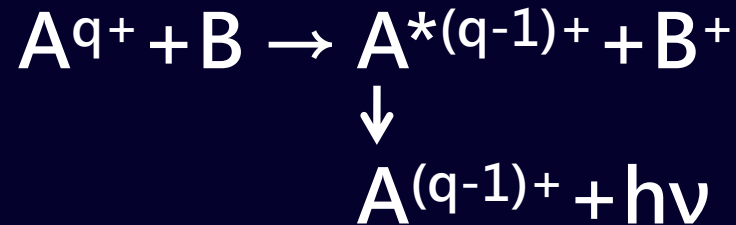
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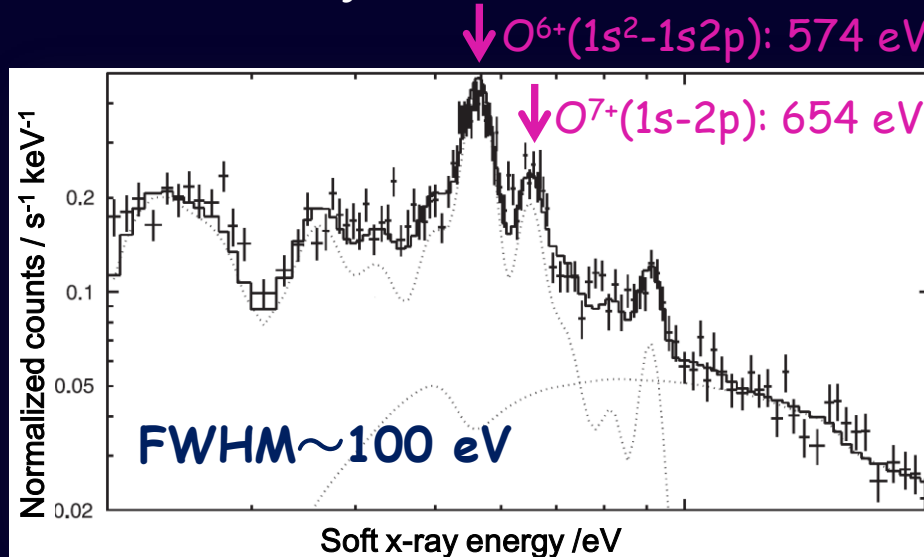
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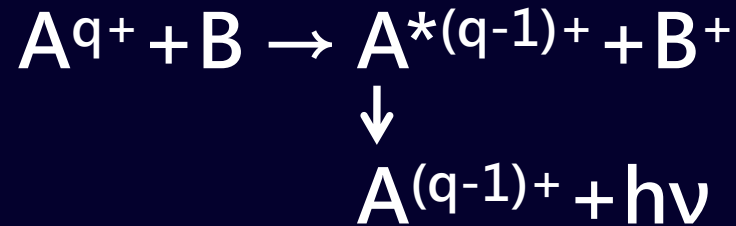
Si(Li)半導体検出器

160 eV @ 5.9 keV



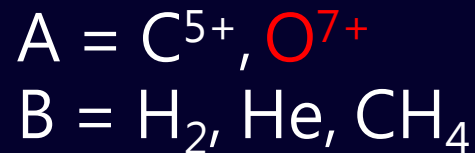
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- 1 電子捕獲断面積
- 等方散乱を仮定した発光断面積

Si(Li)半導体検出器

160 eV@5.9 keV



実験装置

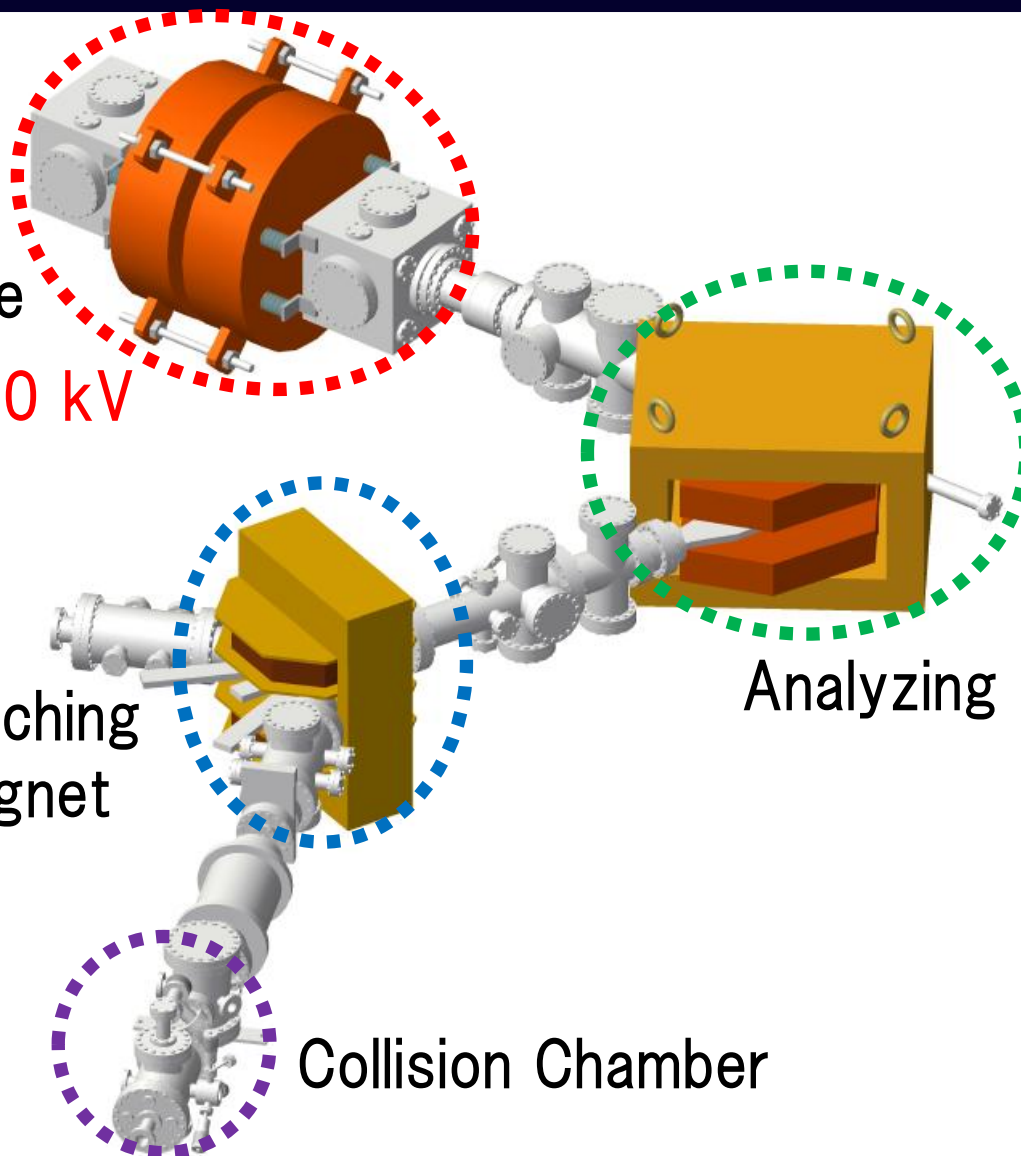
14.25 GHz
ECR Ion Source

5-10 kV

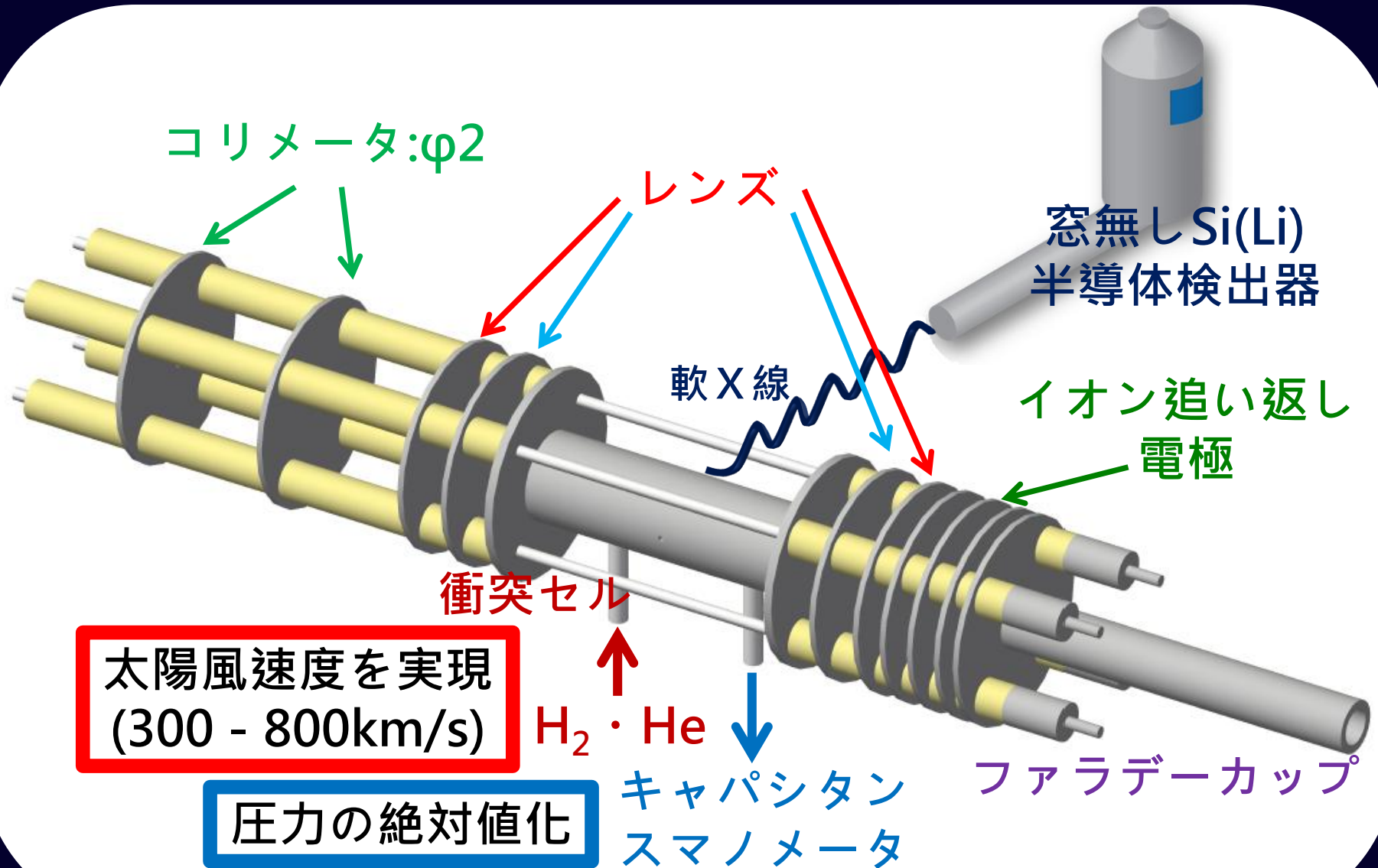
Switching
Magnet

Analyzing Magnet

Collision Chamber



実験装置



減衰法による1電子捕獲断面積

$$\frac{dI}{dx} = -(\sigma n) I \quad I = I_0 \exp(-\sigma n l)$$

$$\text{1回衝突条件} \quad \sigma n l \ll 1$$

$$I \approx I_0 (1 - \sigma n l)$$

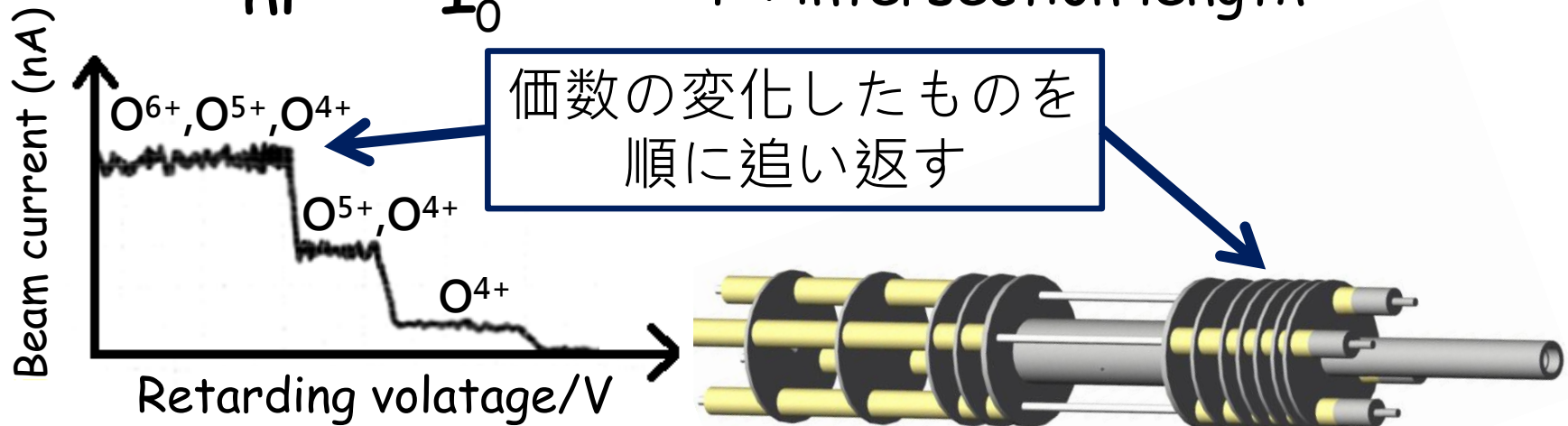
$$\sigma = \frac{1}{n l} \left(1 - \frac{I}{I_0} \right)$$

I : ion current

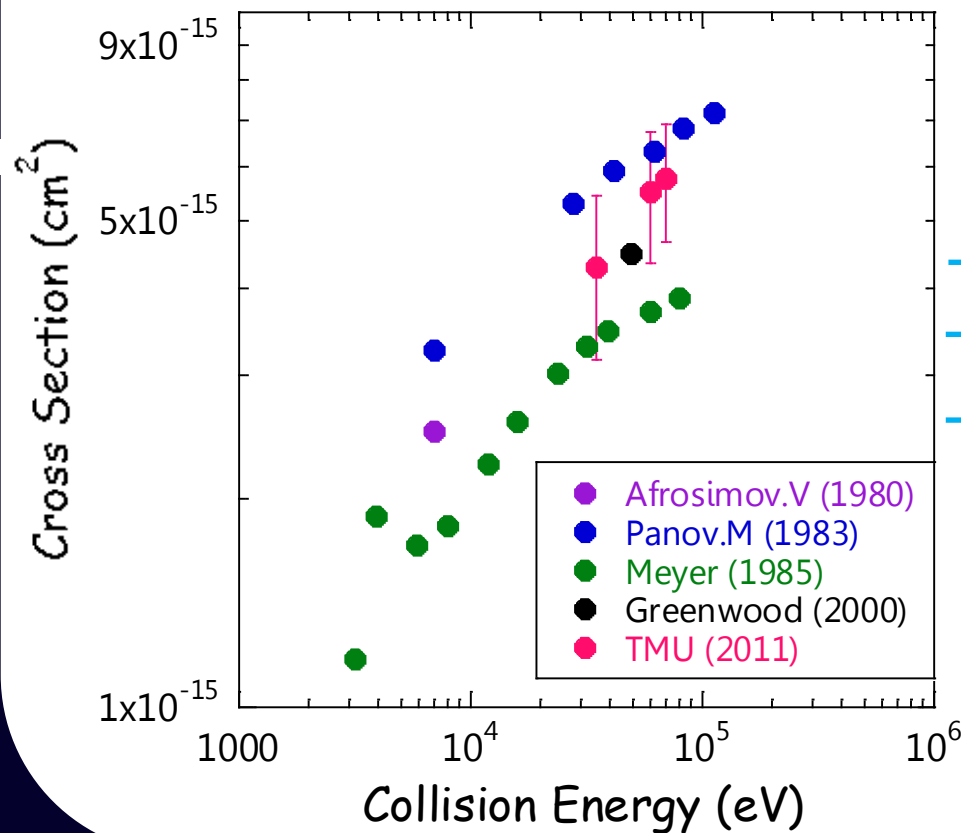
σ : cross section

n : number density of target gas

l : intersection length



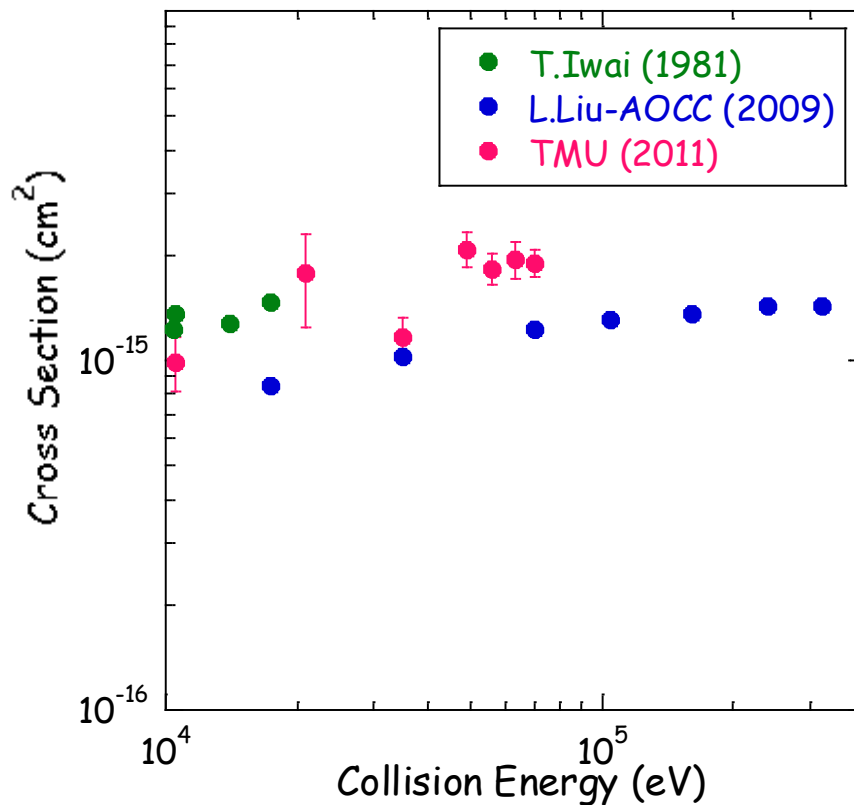
減衰法による 1 電子捕獲断面積



Collision Energy (keV)	Cross Section (cm ²)	Velocity (km/s)	error (%)
70	5.79×10^{-15}	919	19
60	5.53×10^{-15}	647	21
35	4.31×10^{-15}	650	27

減衰法による 1 電子捕獲断面積

$O^{7+}-He$

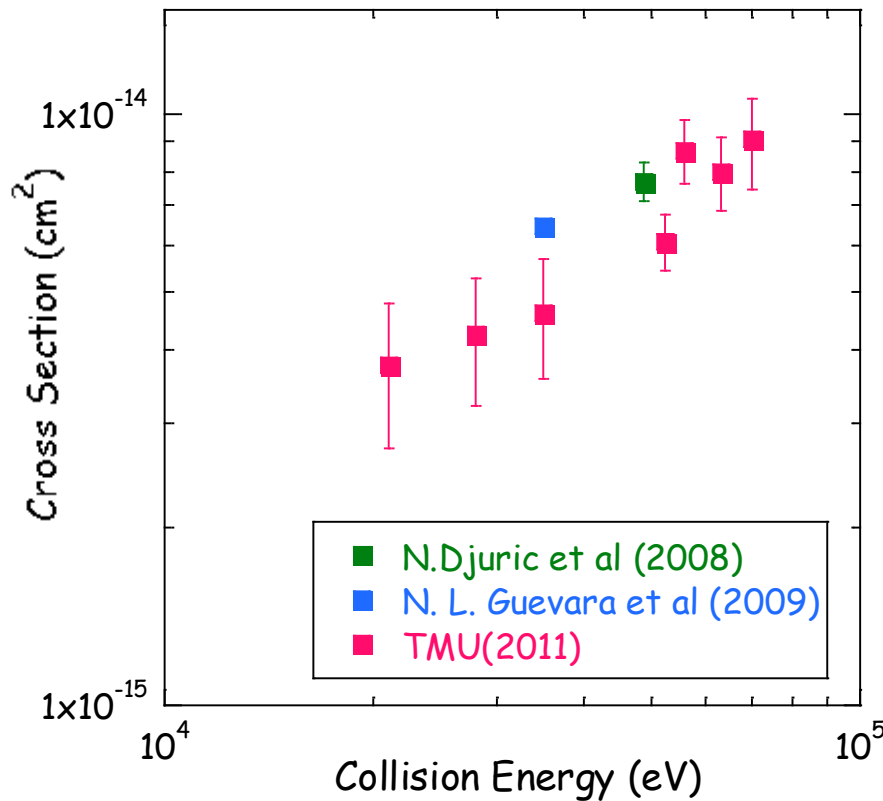


Collision Energy (keV)	Cross Section (cm ²)	Velocity (km/s)	error (%)
70	1.90 × 10 ⁻¹⁵	919	9
63	1.95 × 10 ⁻¹⁵	872	12
56	1.83 × 10 ⁻¹⁵	822	11
49	2.08 × 10 ⁻¹⁵	769	11
35	1.16 × 10 ⁻¹⁵	650	14
21	1.77 × 10 ⁻¹⁵	503	30
10.5	9.92 × 10 ⁻¹⁶	356	18

減衰法による 1 電子捕獲断面積



IP: $\text{H}=\text{CH}_4=13.6 \text{ eV}$

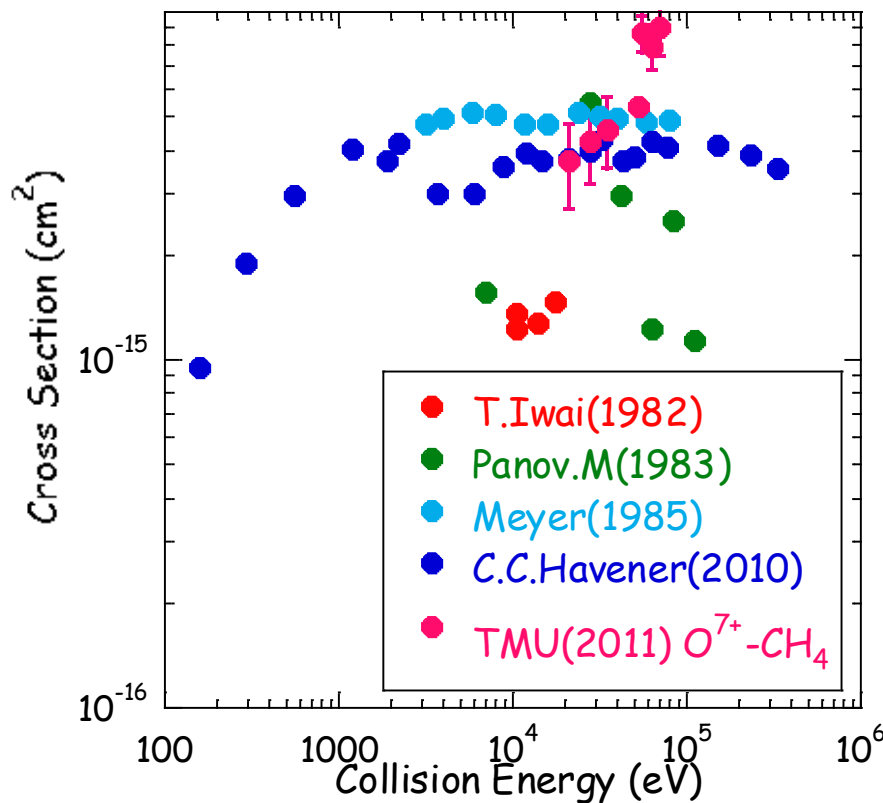


Collision Energy (keV)	Cross Section (cm ²)	Velocity (km/s)	error (%)
70	9.04×10^{-15}	919	17
63	7.99×10^{-15}	872	14
56	8.69×10^{-15}	822	12
52.5	6.09×10^{-15}	796	11
35	4.61×10^{-15}	650	23
28	4.24×10^{-15}	581	24
21	3.75×10^{-16}	503	28

減衰法による1電子捕獲断面積

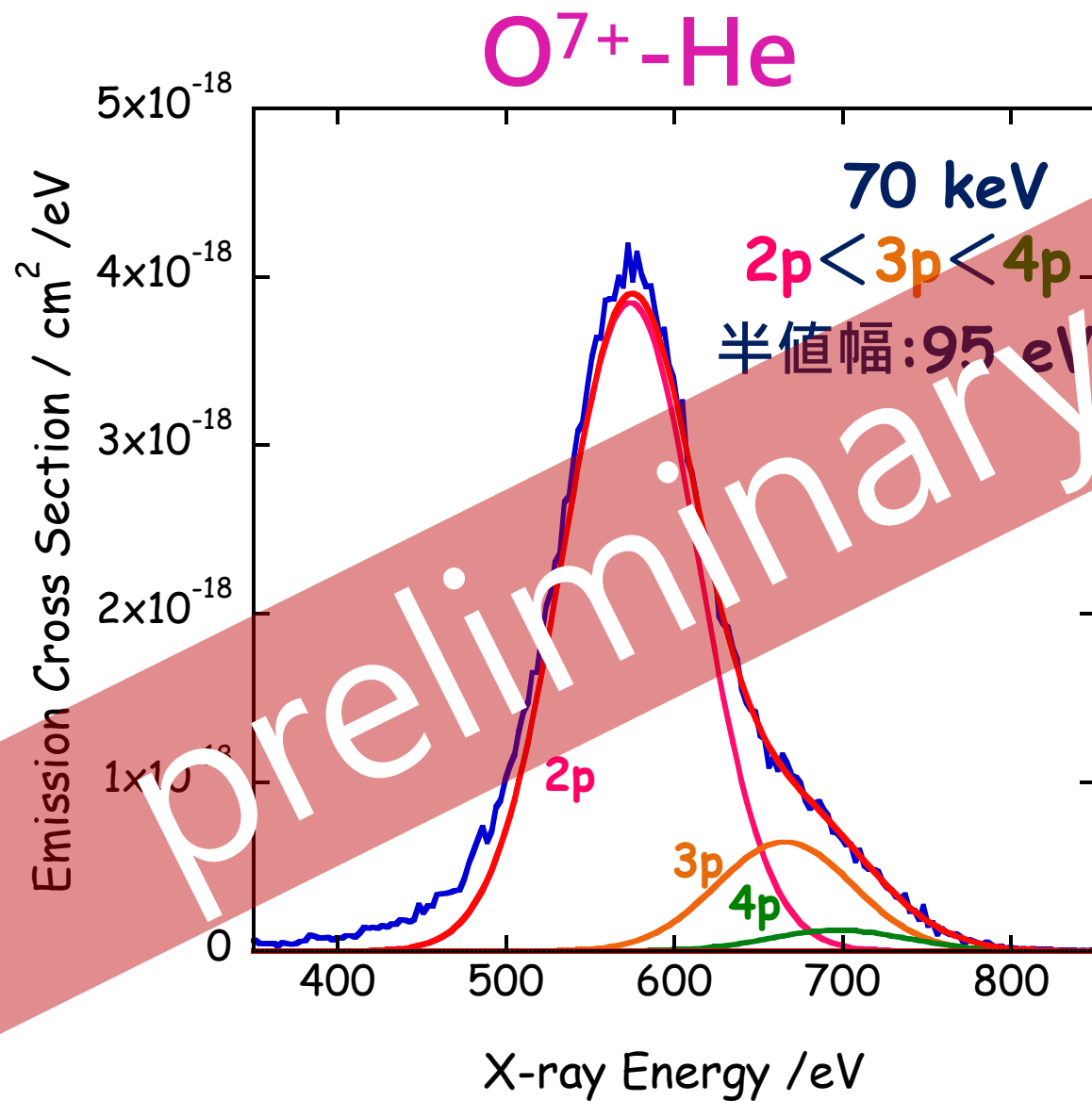


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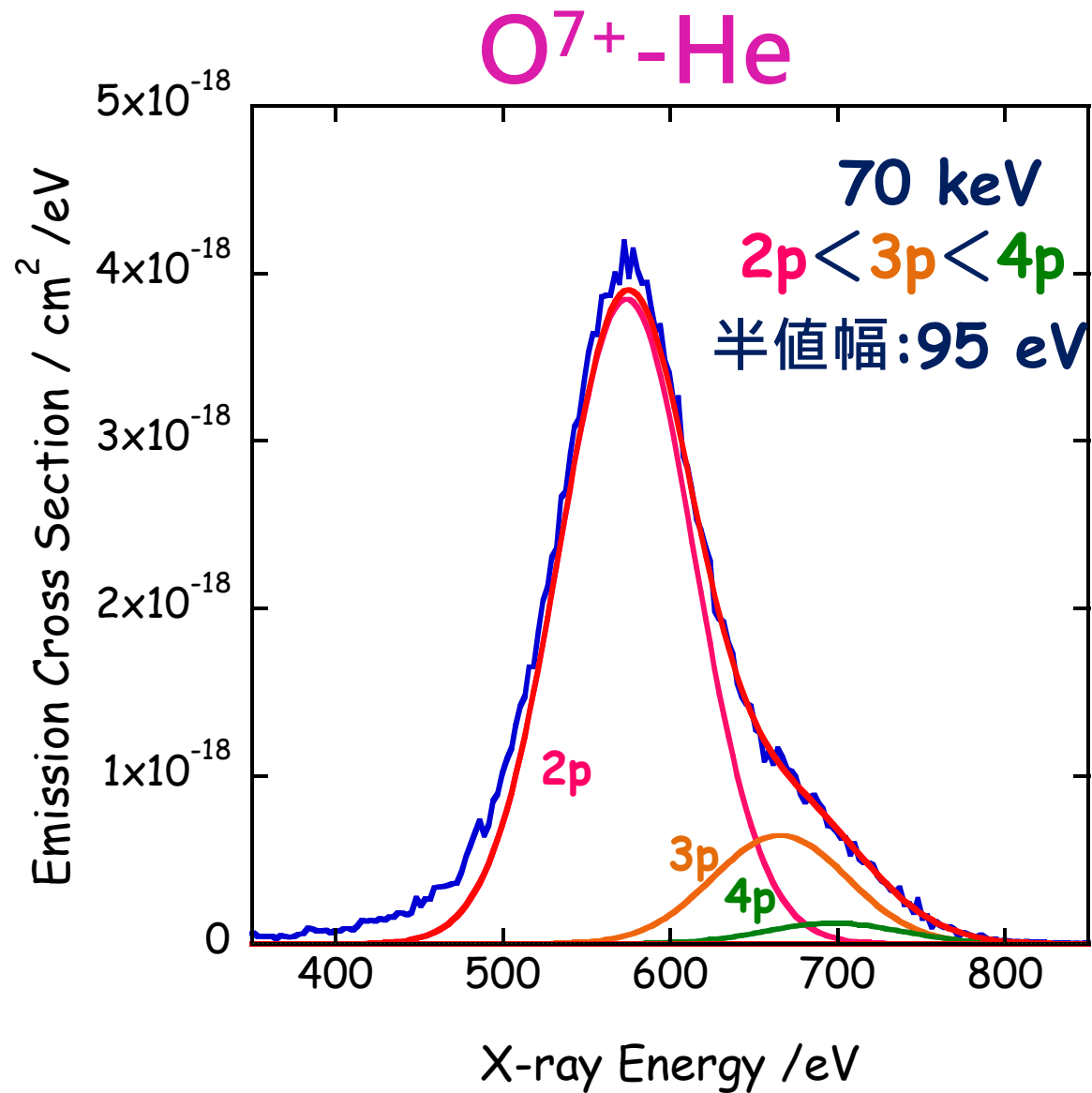


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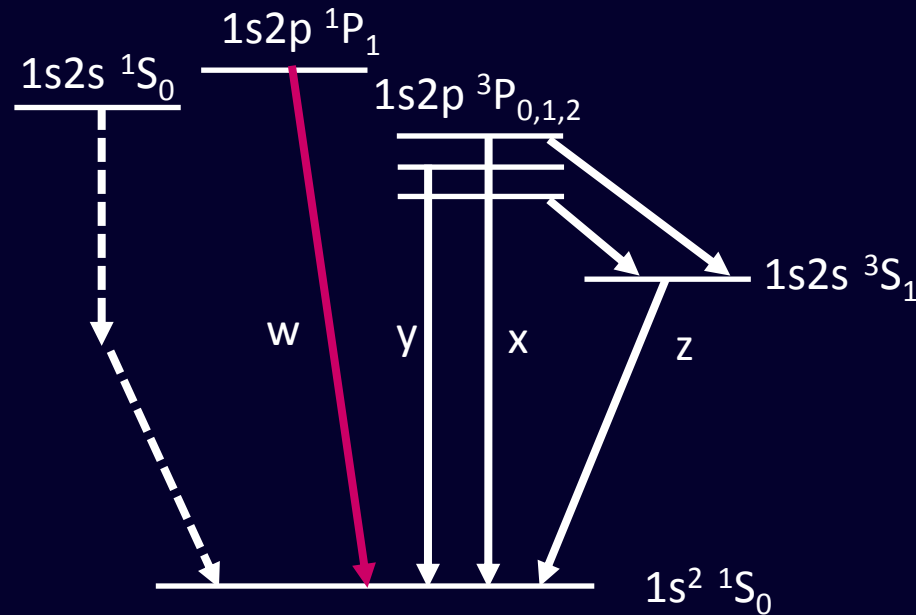
発光断面積



発光断面積

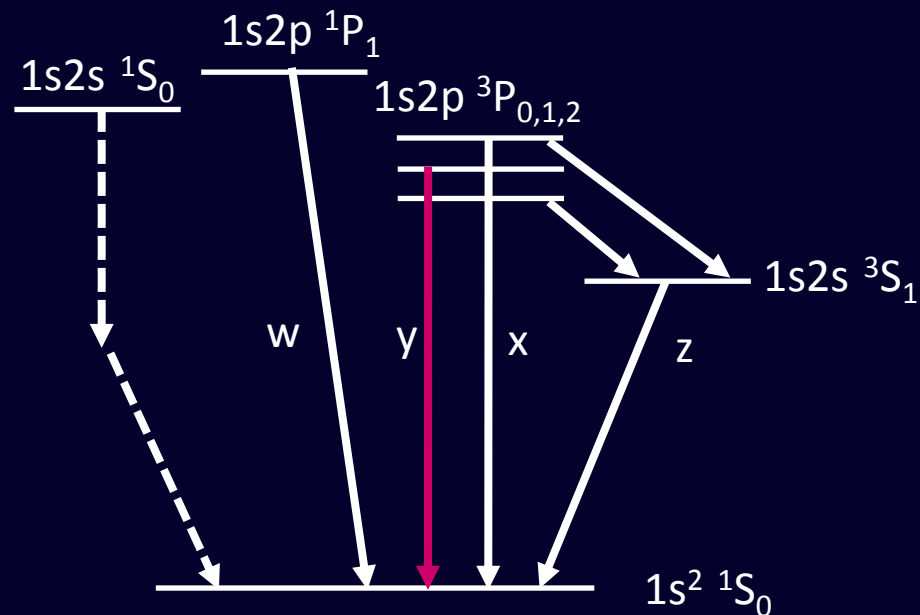


O⁶⁺ Schematic Diagram



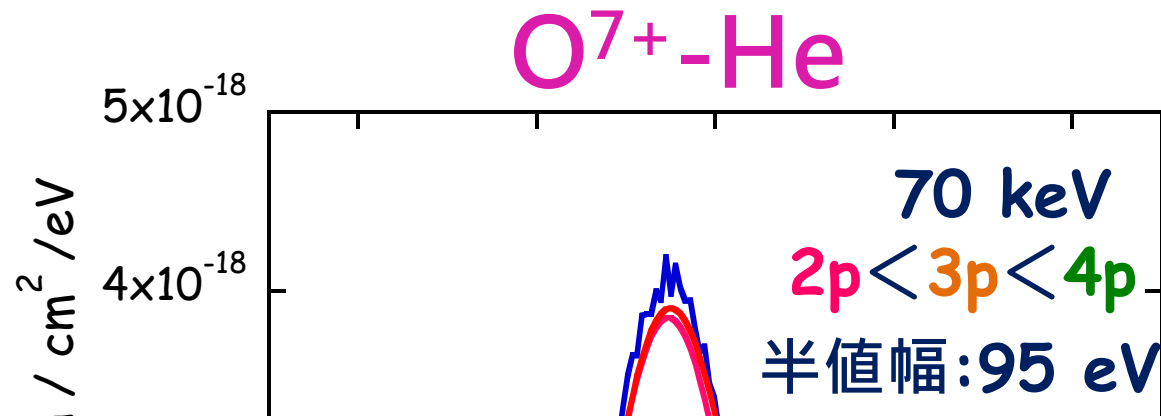
key	transition		wavelength (nm)	life time (s)	wavelength (nm)	life time (s)
			NIST		I.M. Savukov et al.	
w	$1s2p \ ^1P_1 \rightarrow 1s^2 \ ^1S_0$	E1	2.1602	3.02×10^{-13}	2.1600	3.03×10^{-13}
x	$1s2p \ ^3P_2 \rightarrow 1s^2 \ ^1S_0$	M2	2.1804	3.02×10^{-6}	2.1800	3.02×10^{-6}
y	$1s2p \ ^3P_1 \rightarrow 1s^2 \ ^1S_0$	E1	-	-	2.1802	1.87×10^{-9}
z	$1s2s \ ^3S_1 \rightarrow 1s^2 \ ^1S_0$	M1	2.2101	9.56×10^{-4}	2.2097	9.61×10^{-4}

O⁶⁺ Schematic Diagram

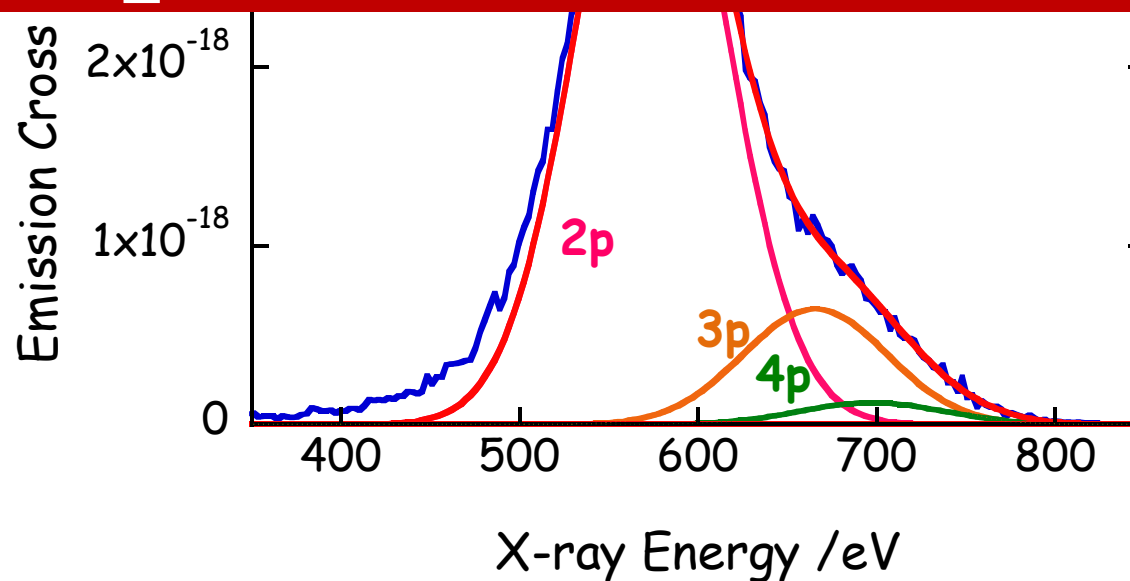


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z	$1s2s \ ^3S_1 \rightarrow 1s^2 \ ^1S_0$	M1	2.2101	2.2097	9.56×10^{-4}	9.61×10^{-4}

発光断面積



$3P_1$, $1P_1$ 両方からの発光が見える

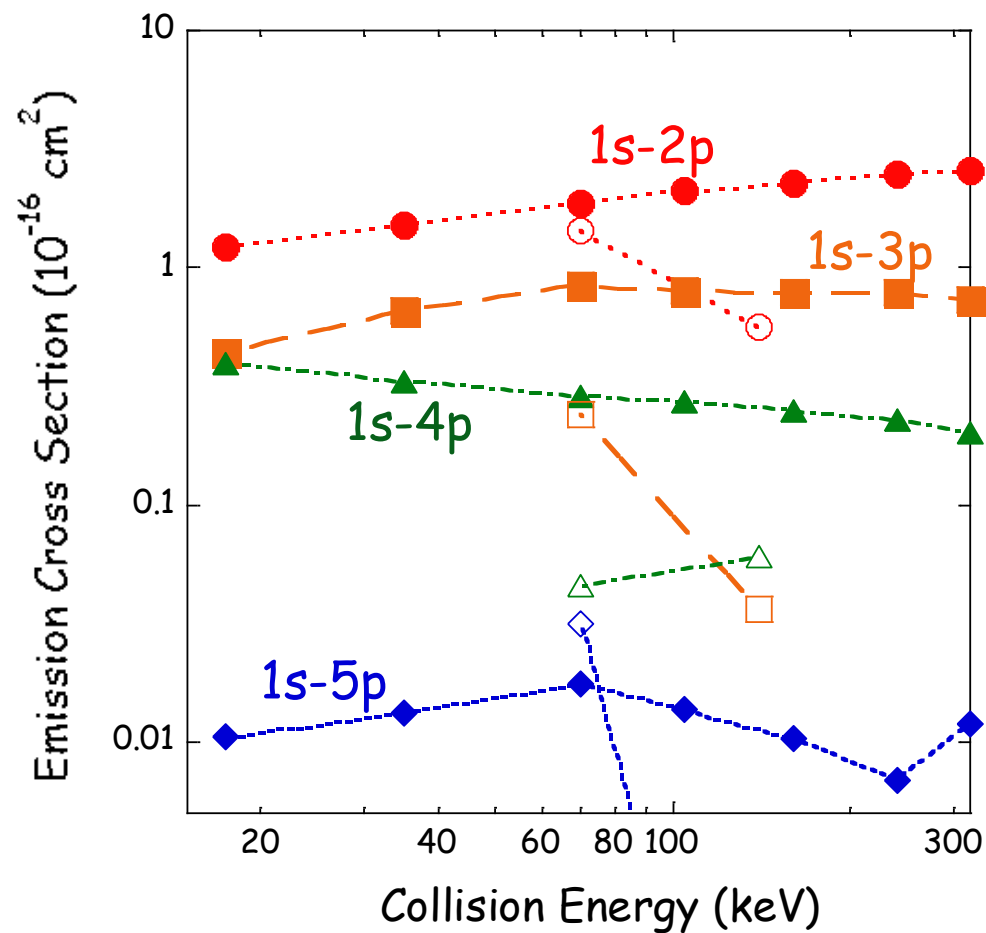


発光断面積

$O^{7+}-He$

●■▲◆ : AOCC法理論計算

○□△◇ : 実験結果



まとめ

Projectile : C^{5+} , O^{7+}

Target : He, H_2 , CH_4

- 電荷移行断面積の測定
いずれも過去のデータ, 理論計算に一致
- 発光断面積の測定
等方散乱を仮定 / 3P_1 , 1P_1 の両方が発光

今後

- projectile : C^{6+} , N^{7+} , O^{8+}
- Magic Angle方向(54.7°)からのX線観測
→偏光度に依存しない発光断面積の測定
- X線集光レンズを用いた測定
- 準安定状態の発光を観測
→kingdon trapの使用

発光断面面積

$$\sigma[\text{cm}^2] = \frac{R[/\text{m}^3 \cdot \text{s}]}{n[/\text{m}^3] \cdot J[/\text{cm}^2 \cdot \text{s}]}$$

$$R[/\text{m}^3 \cdot \text{s}] = \boxed{m} \cdot \frac{\boxed{4\pi r^2[\text{mm}^2]}}{\boxed{S[\text{mm}^2]}} \cdot \frac{\boxed{1}}{\boxed{t[\text{s}]}} \cdot \frac{\boxed{1}}{\boxed{4/3\pi r^3[\text{m}^3]}}$$

↓
solid angle
↓
emission volume

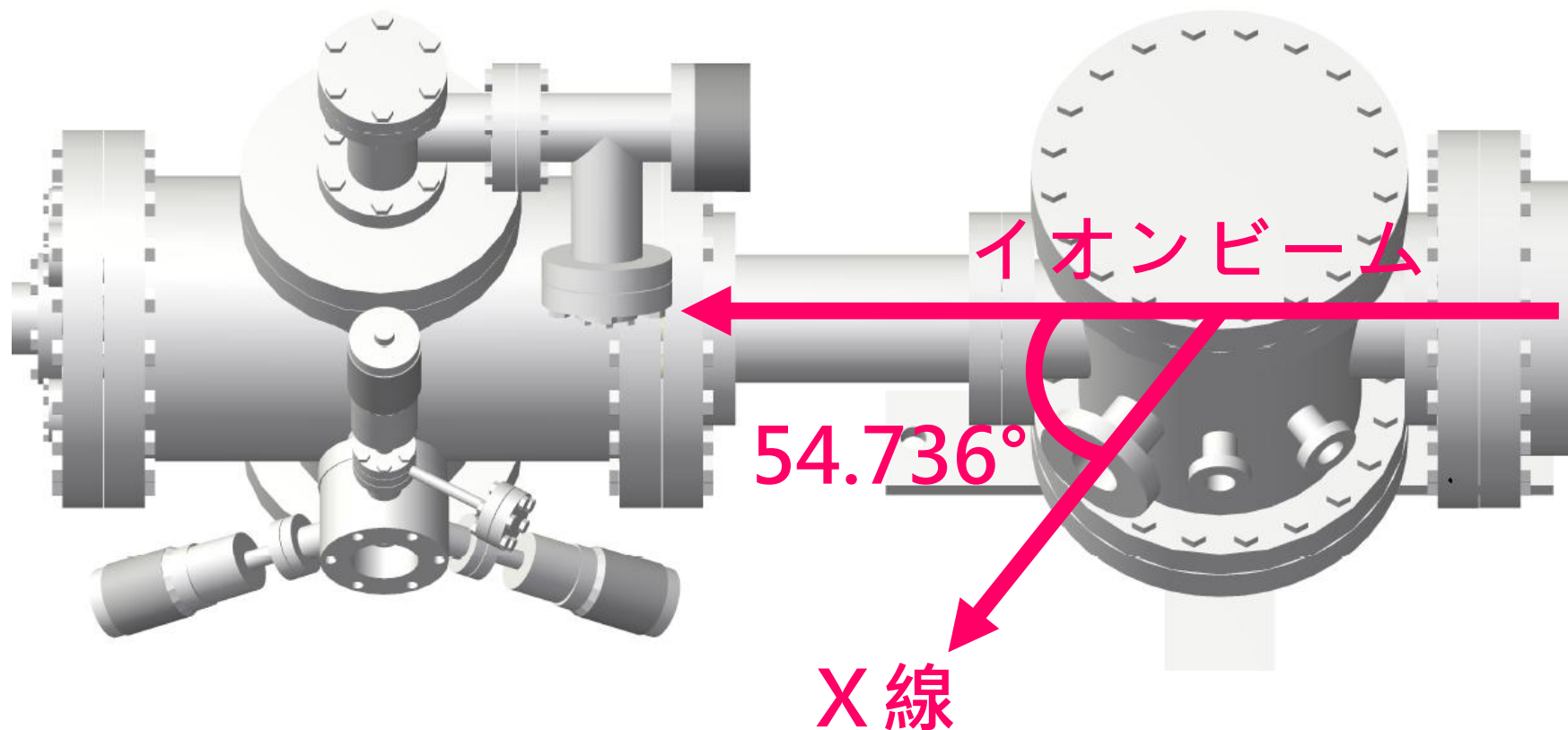
number of event
measurement time

$$J[/\text{cm}^2 \cdot \text{s}] = \boxed{I[\text{A}]} \cdot \boxed{e[/\text{A} \cdot \text{s}]} \cdot \frac{\boxed{1}}{\boxed{q}} \cdot \frac{\boxed{1}}{\boxed{\pi r^2[\text{cm}^2]}}$$

beam elementary current
charge
↓
projectile charge
beam diameter

M a g i c a n g l e

励起状態からの発光強度分布
→ 偏光度に依存しない発光強度



M a g i c a n g l e

励起状態からの発光強度分布
→偏光度に依存しない発光強度

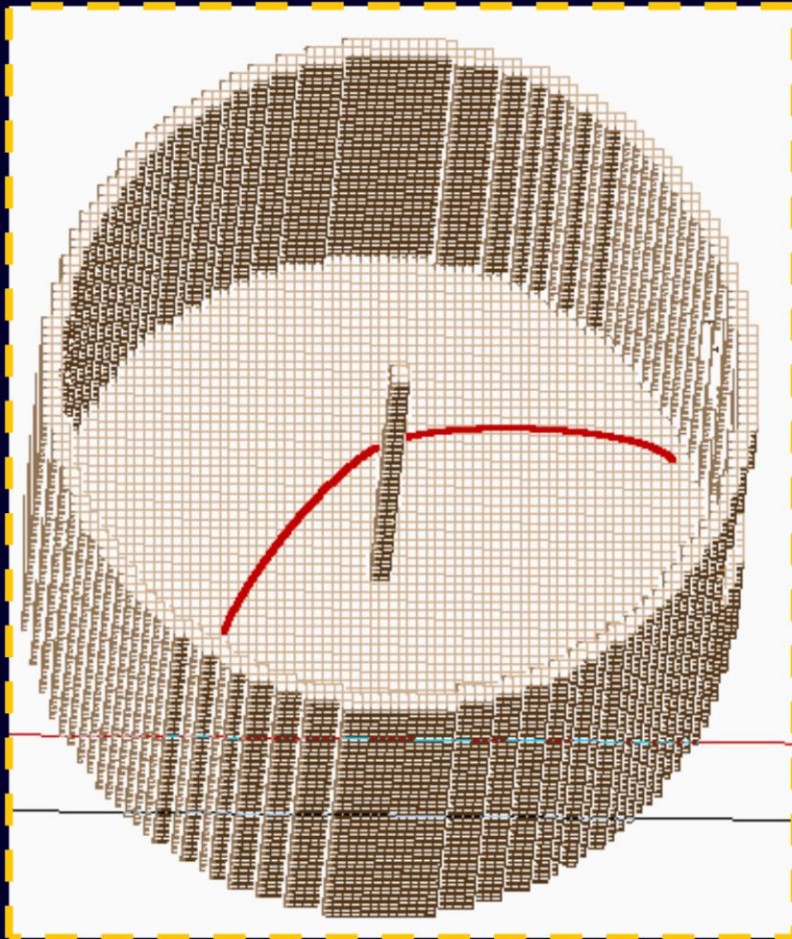
$$I(\theta) = \frac{1}{4\pi} [1 + \alpha_2 A_{20} P_2(\cos\theta)]$$

α_2 : 角運動量に依存するパラメータ
 A_{20} : 偏光度に依存するパラメータ

$$P_2(\cos\theta) = 0 \Leftrightarrow 3\cos^2\theta - 1 = 0$$

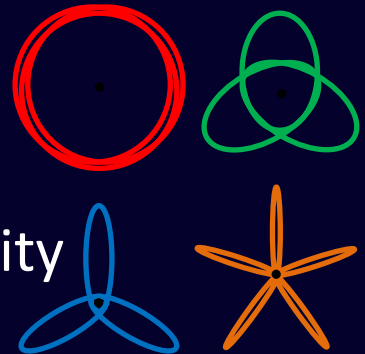
$$\underline{\theta = 54.736^\circ}$$

~Kingdon Trap~



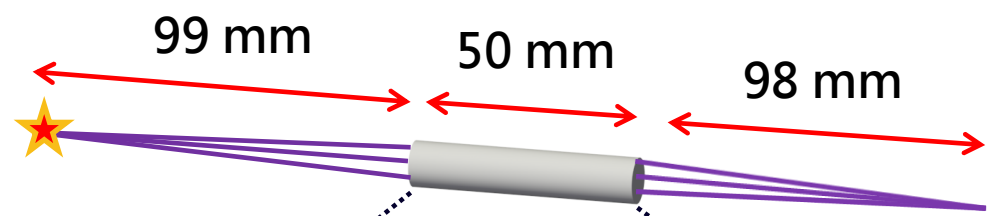
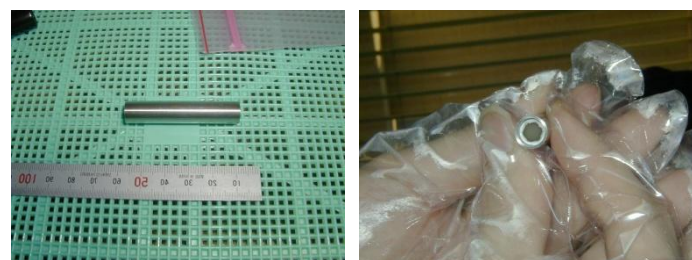
feature

- without the use of either magnetic fields or rf fields
- no potential minimum
- it consists of three electrodes
 - central wire
 - outer cylinder
 - two end caps
- dynamical stability



X線集光レンズ

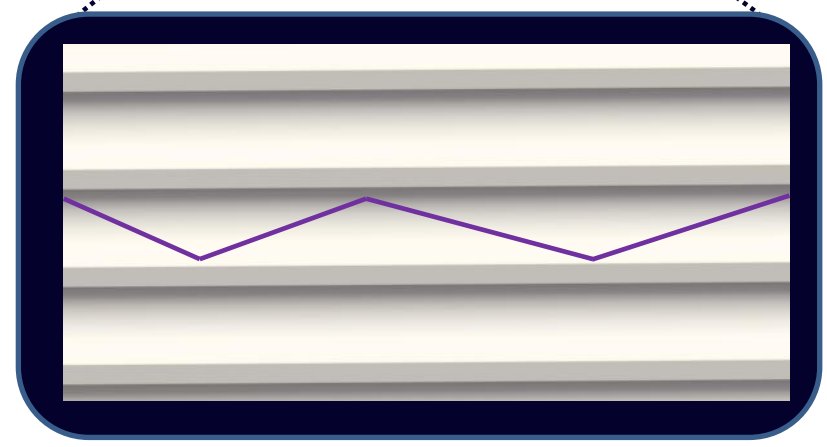
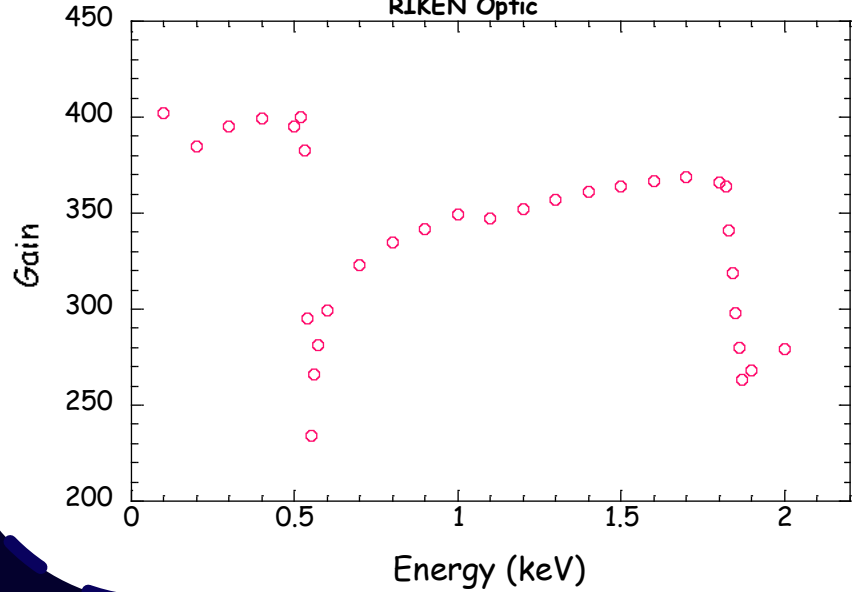
Polycapillary Optics FOR MICRO X-RAY FLUORESCENCE AND X-RAY DIFFRACTION



Gain vs. Energy (keV)

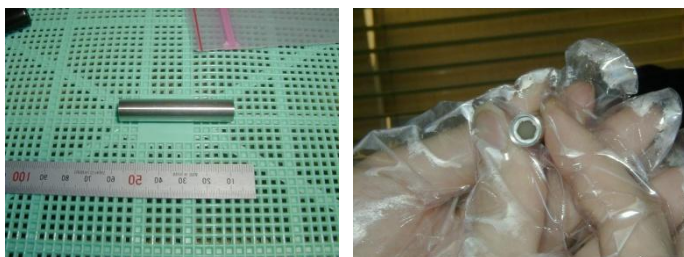
(Base case of 300um pinhole 250mm away from a 500um input source)

RIKEN Optic



X線集光レンズ

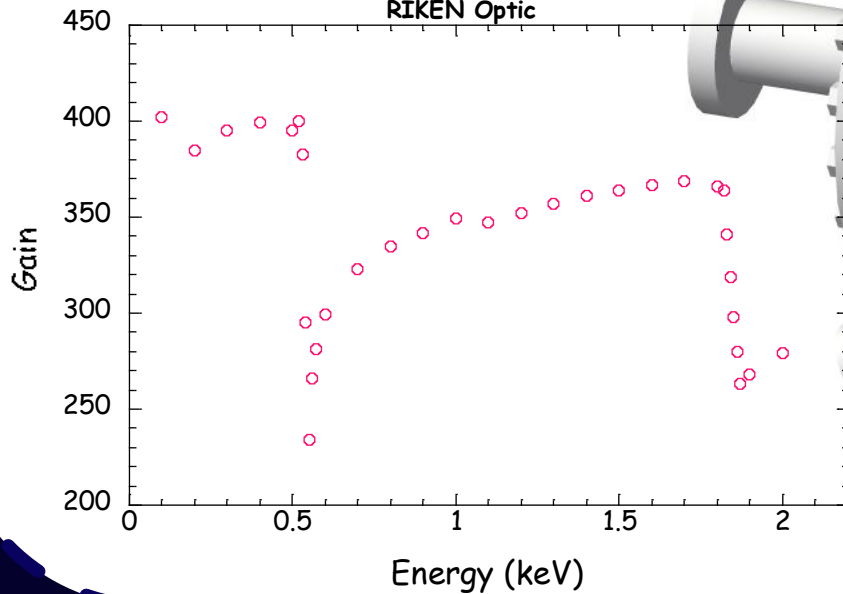
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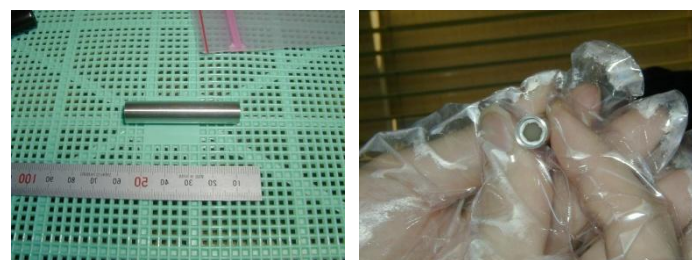
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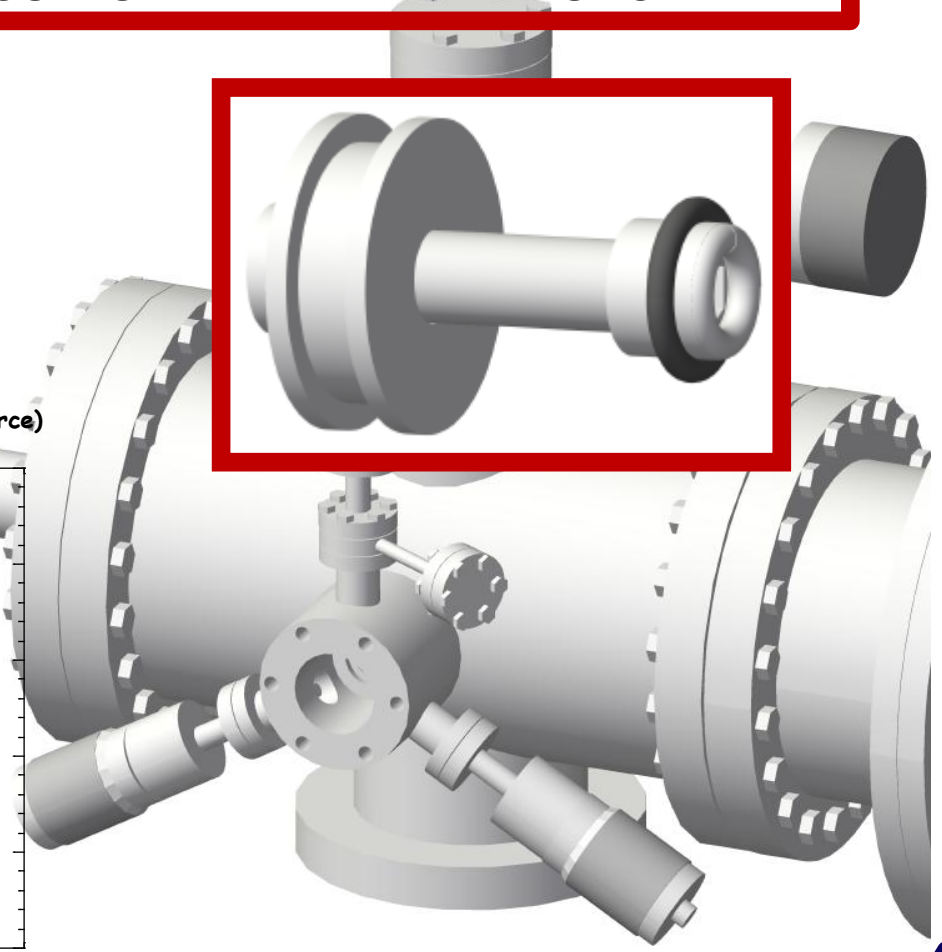
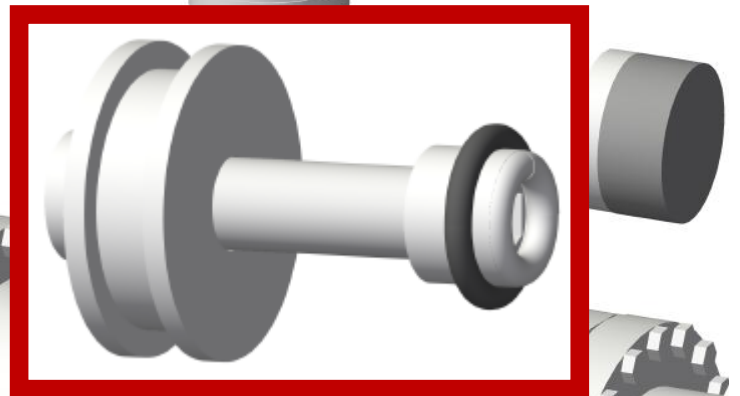
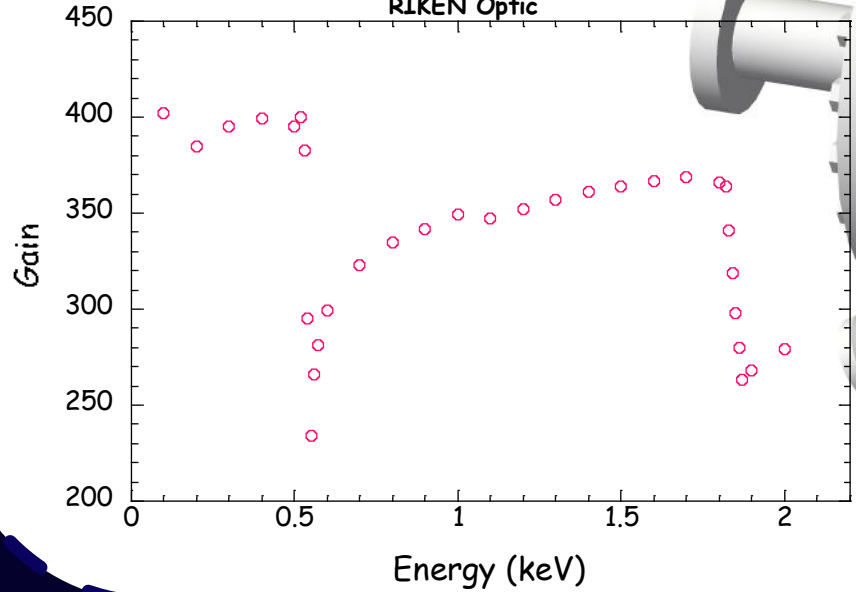
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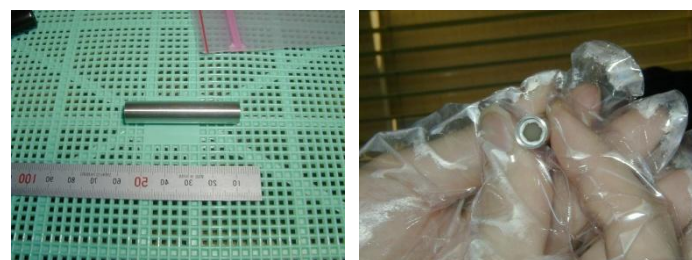
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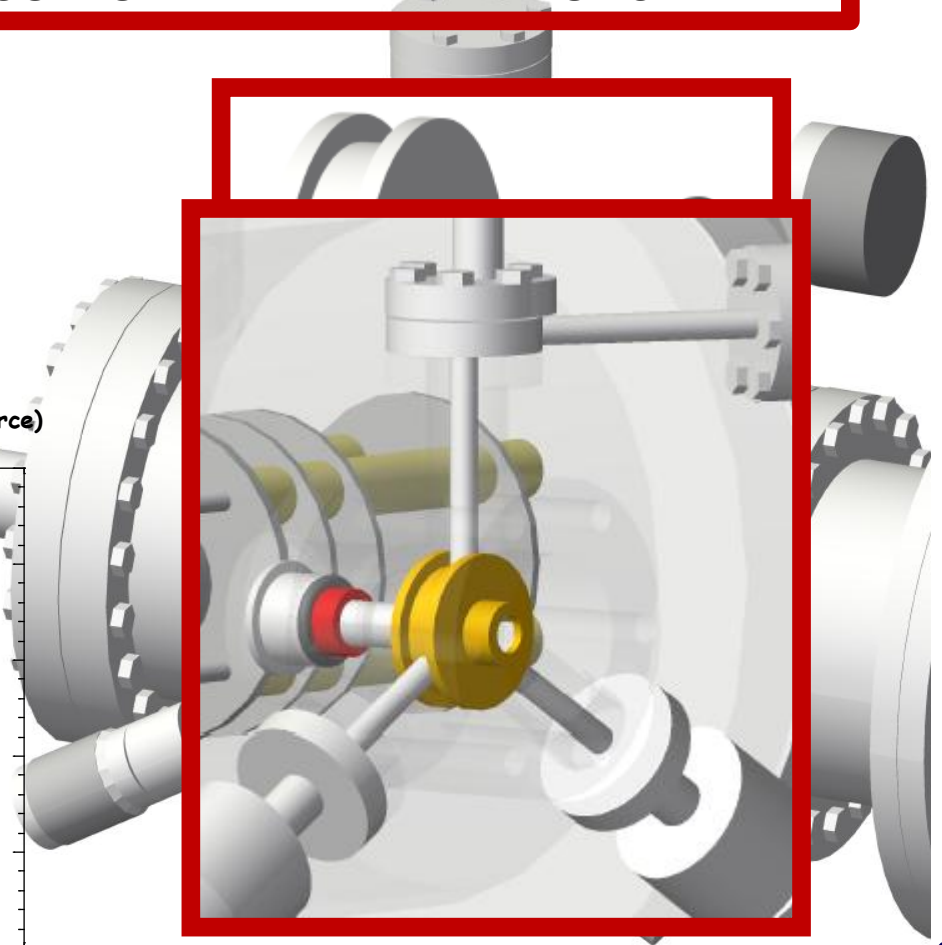
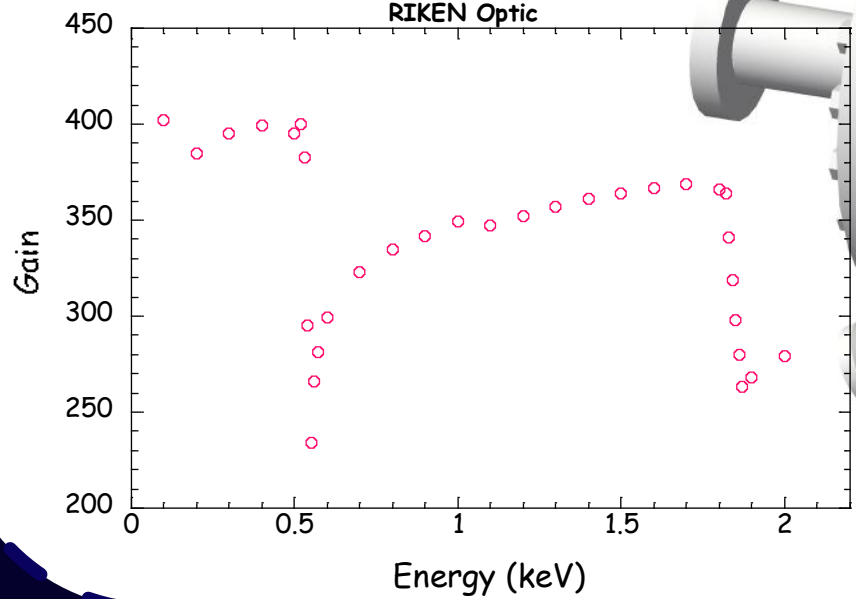
Polycapillary Optics FOR MICRO X-RAY FLUORESCENCE AND X-RAY DIFFRACTION



Gain vs. Energy (keV)

(Base case of 300um pinhole 250mm away from a 500um input source)

RIKEN Optic



$3P_1$

状

態

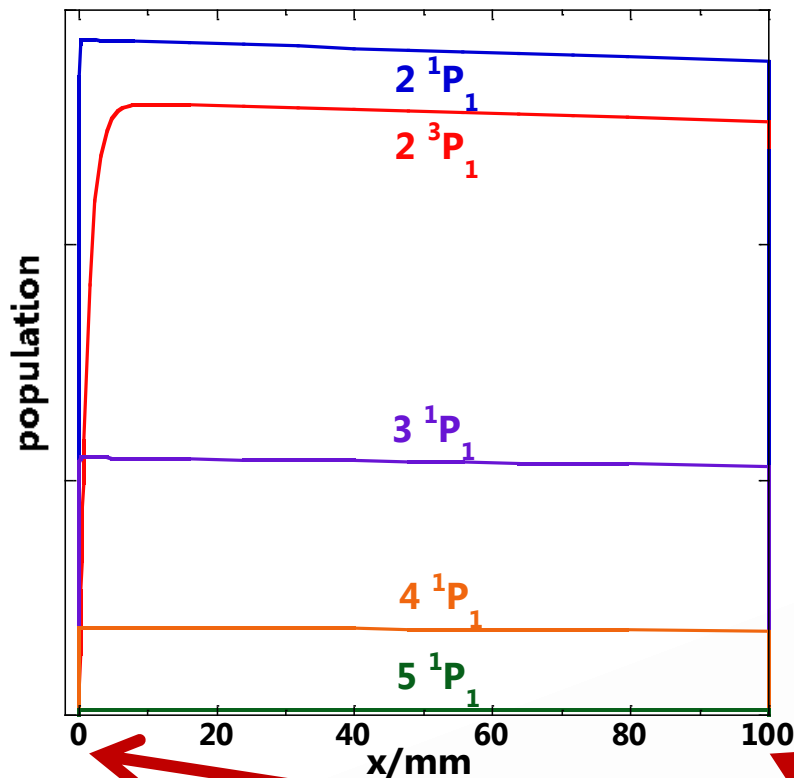
か

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発

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$$\frac{d[nls]}{dt} = \sigma v [\text{ion}] n - \sum_f A_{if} [nls] + \sum_i A_{if} [n'l's']$$

[nls], [ion] : number density
 σ : charge transfer cross section
 by AOCC method (L. Liu)
 v : ion velocity
 n : number density of target gas
 A : Einstein coefficient

グラフの横軸は衝突セルの長さに対応

