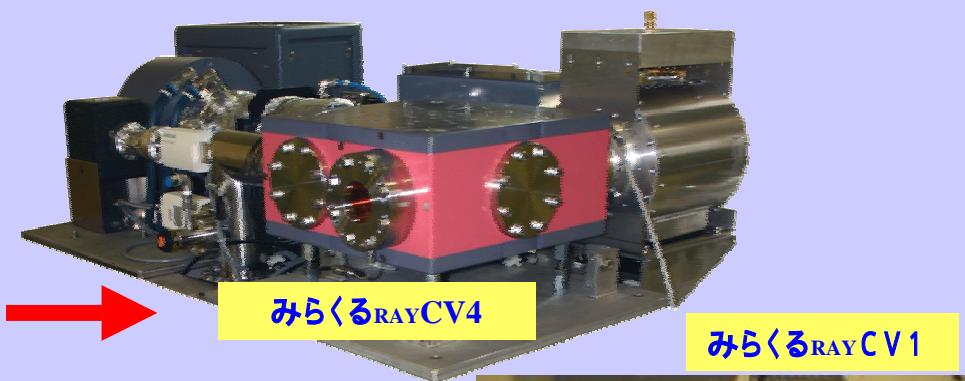


日本物理学会 第64回年次大会シンポジューム
小型加速器の新展開とその応用

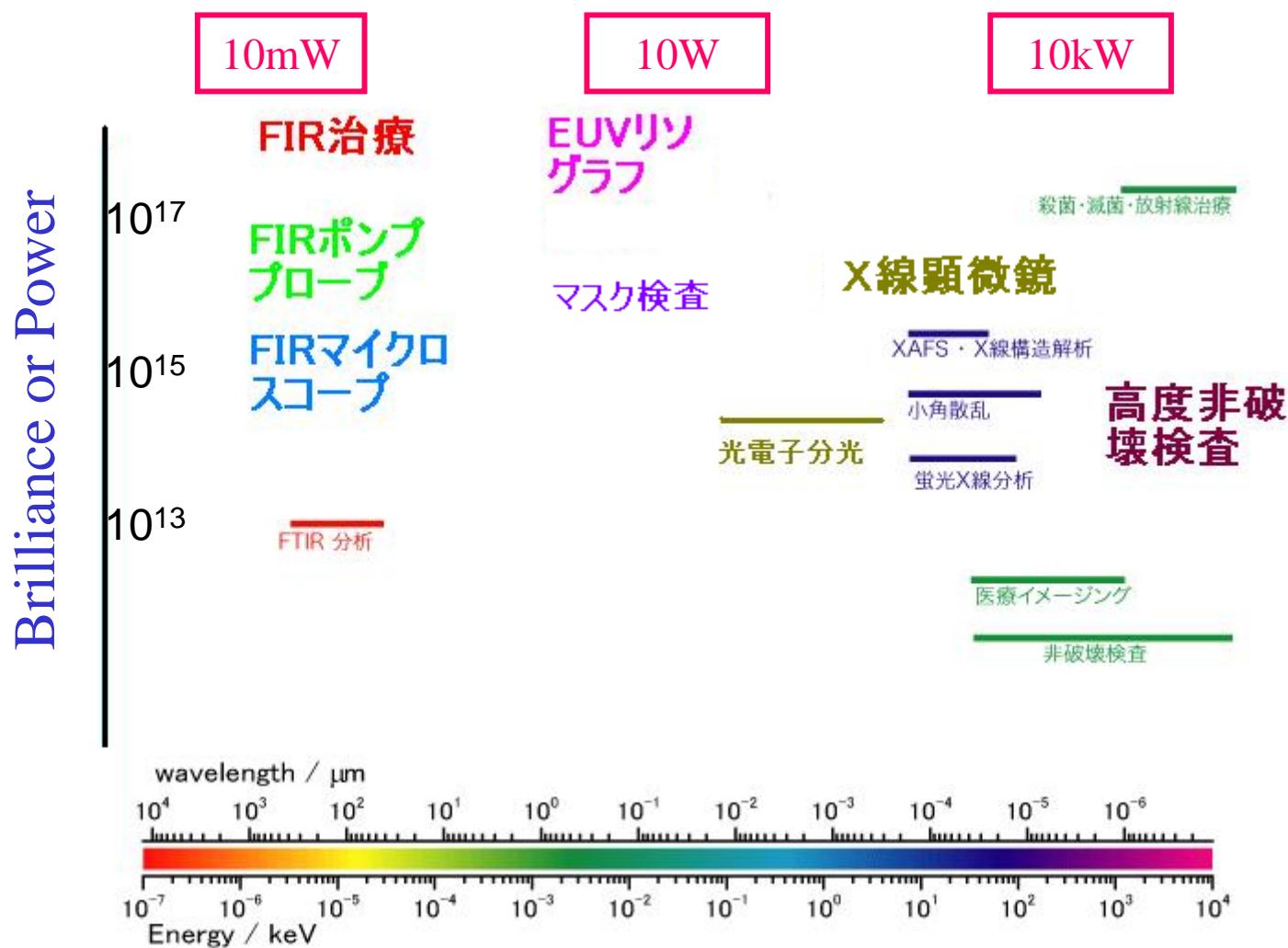
さらに小型化した卓上型放射光装置 そのパワーと利用の展開



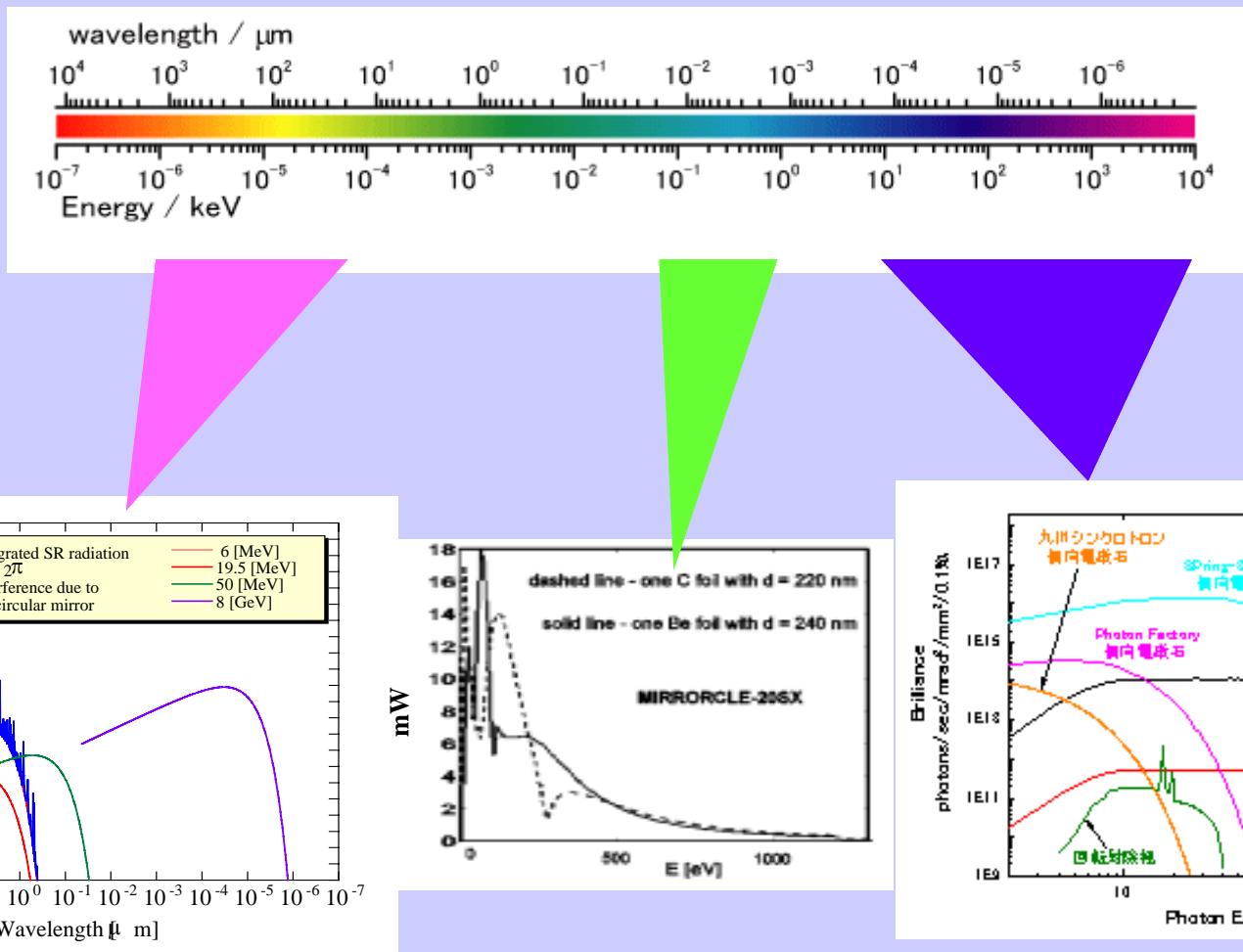
みらくる



電磁波利用の(パワー / 波長)相関



様々な光を発生する“みらくる”



赤外・遠赤外線放射光パワー



MIRRORCLE 6X (6FIR)

Bolometer

FT-IR

FIR window

Photon storage ring FIR laser system

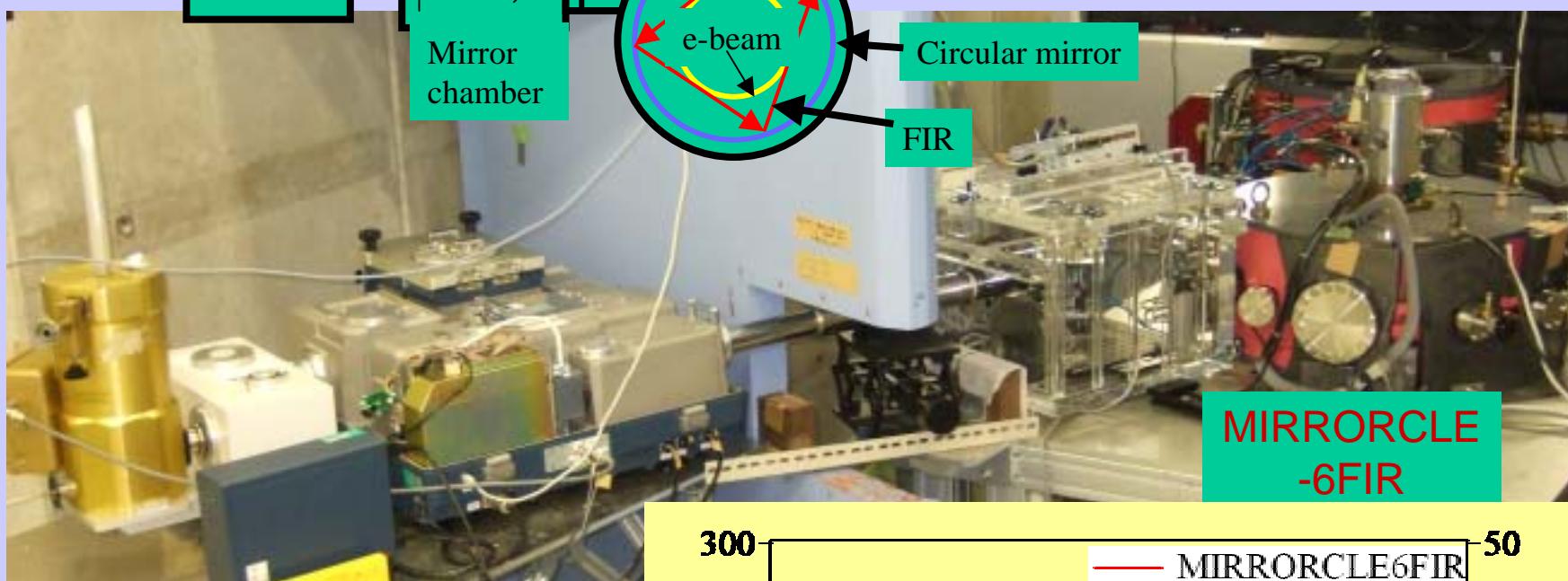


Mirror chamber

e-beam

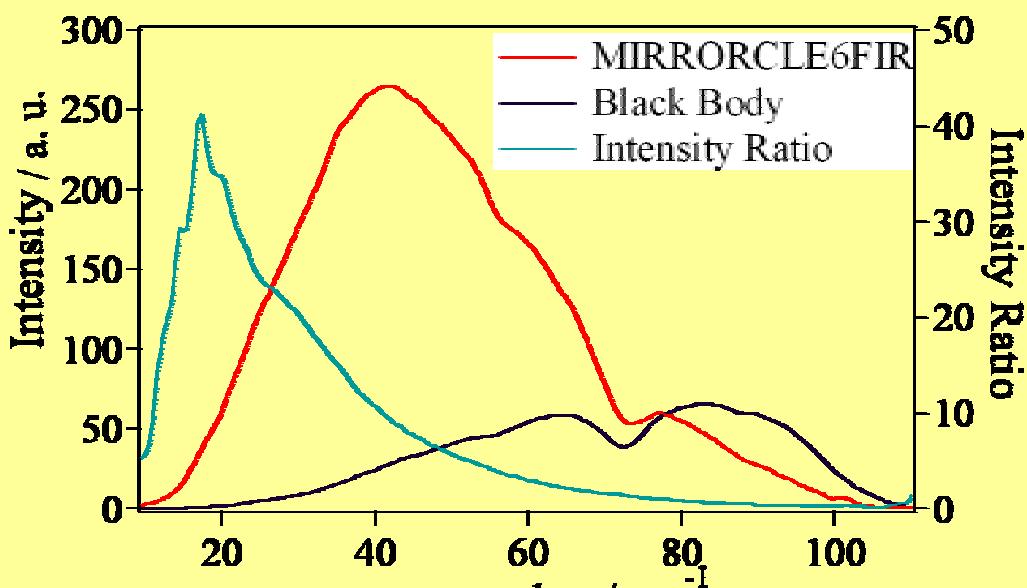
Circular mirror

FIR

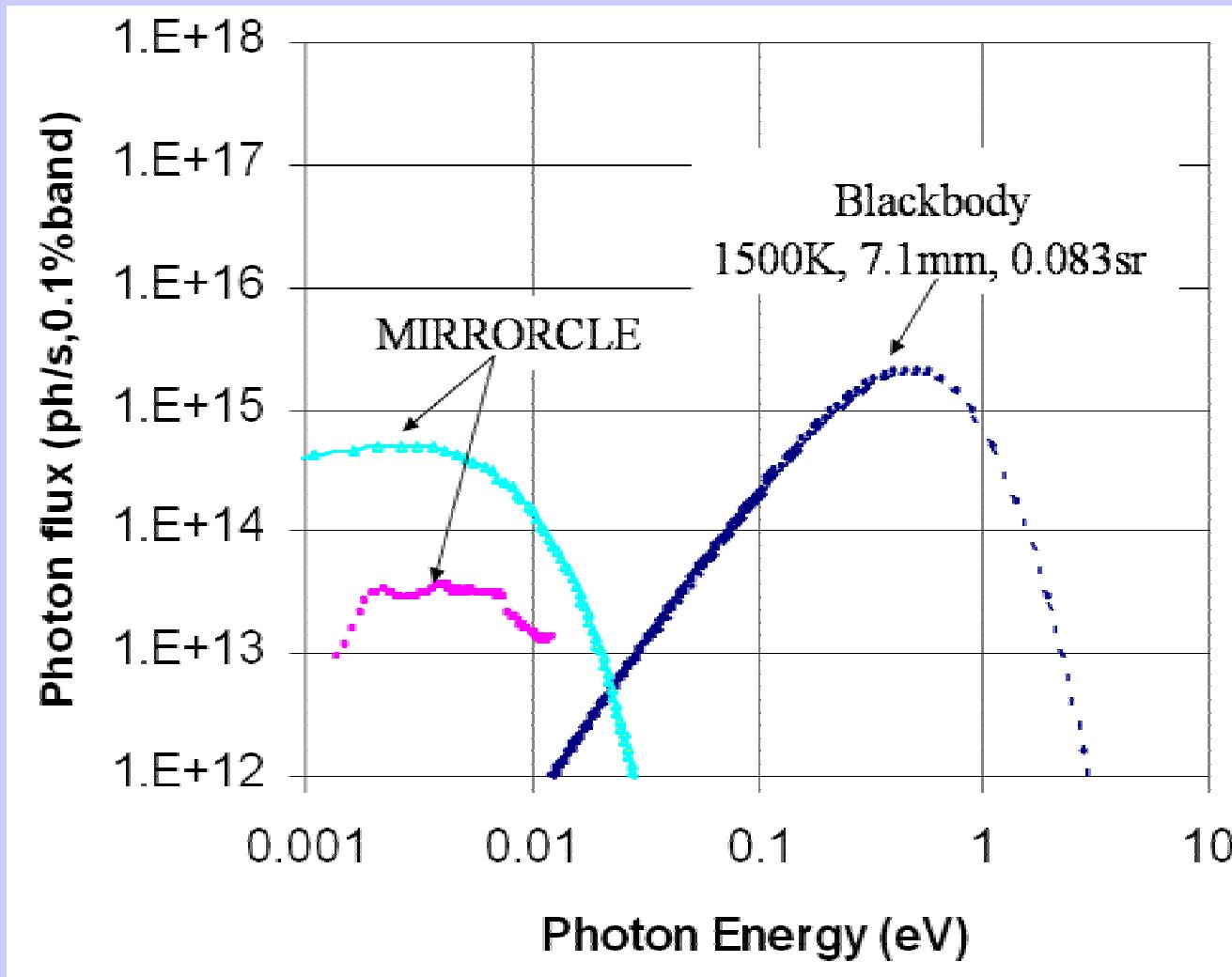


MIRRORCLE
-6FIR

J. Synchrotron Rad. (2009). 16, 299–306
“Performance of the far-IR beam line of
the 6 MeV tabletop
synchrotron light source”
Md. Monirul Haque, Hironari Yamada,
Ahsa Moon and Mami Yamada



Photon flux from 6MeV PhSR measured through 2mm iris

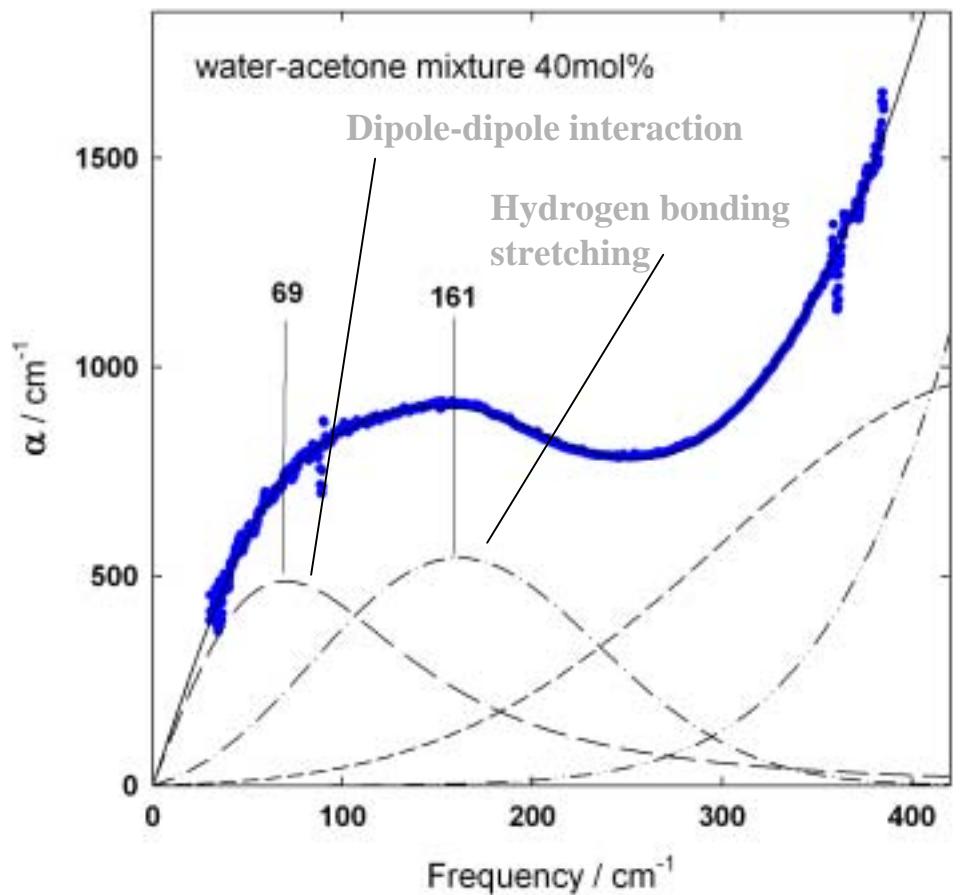
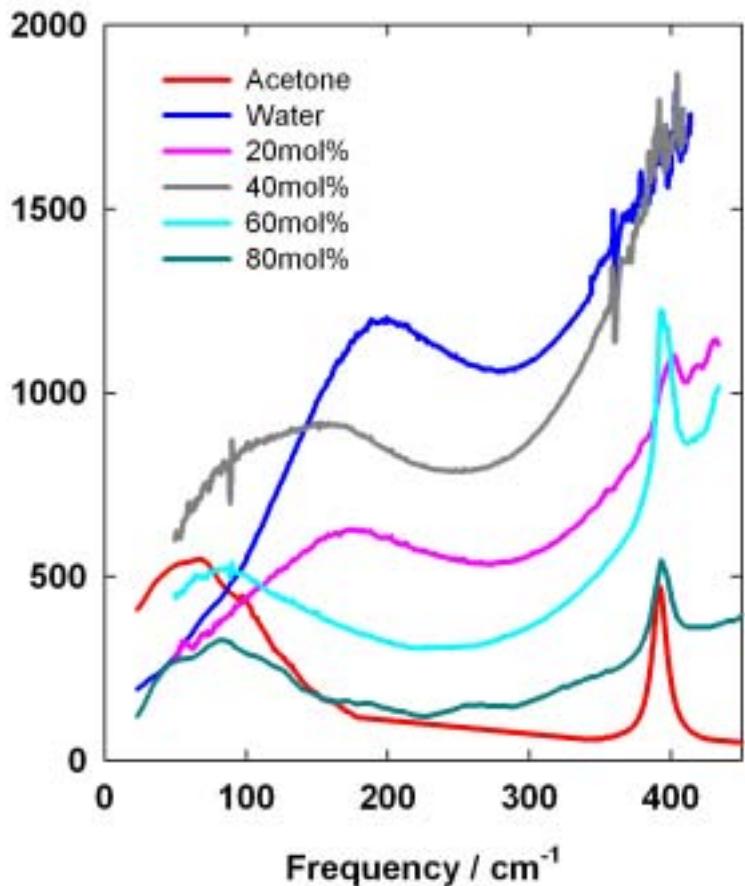


Comparison with other sources

SR source	Photon flux (ph/sec, 0.1% band)			
	$\lambda=10\mu\text{m}$	$\lambda=100\mu\text{m}$	$\lambda=500\mu\text{m}$	$\lambda=1000\mu\text{m}$
MIRRORCLE-6FIR (calculated) (measured)	..... .....	$\sim 7.85 \times 10^{13}$ $\sim 1.32 \times 10^{13}$	$\sim 5.08 \times 10^{14}$ $\sim 3.06 \times 10^{13}$	$\sim 4.15 \times 10^{14}$ $\sim 1.38 \times 10^{12}$
Spring-8 (Kimura et al., 2001)	$\sim 1 \times 10^{13}$	$\sim 3 \times 10^{11}$	.....	.....
UVSOR-II (Kimura et al., 2006)	$\sim 2 \times 10^{14}$	$\sim 1 \times 10^{14}$	$\sim 2 \times 10^{13}$	$\sim 6 \times 10^{12}$
NSLS (Williams, 2002)	$\sim 10^{12}$	$\sim 10^{13}$	$\sim 10^{14}$	$\sim 10^{14}$
Tohoku-300 MeV linac (Ishi et al., 1991)	.....	$< 10^{10}$	$\sim 1 \times 10^{13}$	$\sim 3 \times 10^{13}$
MLS (Muller et al., 2006)	$\sim 2 \times 10^{14}$	$\sim 8 \times 10^{13}$	$\sim 3 \times 10^{13}$	$\sim 2 \times 10^{13}$
SSLS (Bahou et al., 2007)	$\sim 3 \times 10^{13}$	$\sim 1 \times 10^{13}$	$\sim 8 \times 10^{12}$	$\sim 4 \times 10^{12}$
ALS (Barry et al., 2002)	.....	$\sim 7 \times 10^{12}$	$\sim 4 \times 10^{12}$	$\sim 2 \times 10^{12}$
SOLEIL (calculated) (Dumas et al., 2006)	$\sim 1 \times 10^{14}$	$\sim 4 \times 10^{13}$	$\sim 1 \times 10^{13}$	$\sim 9 \times 10^{12}$

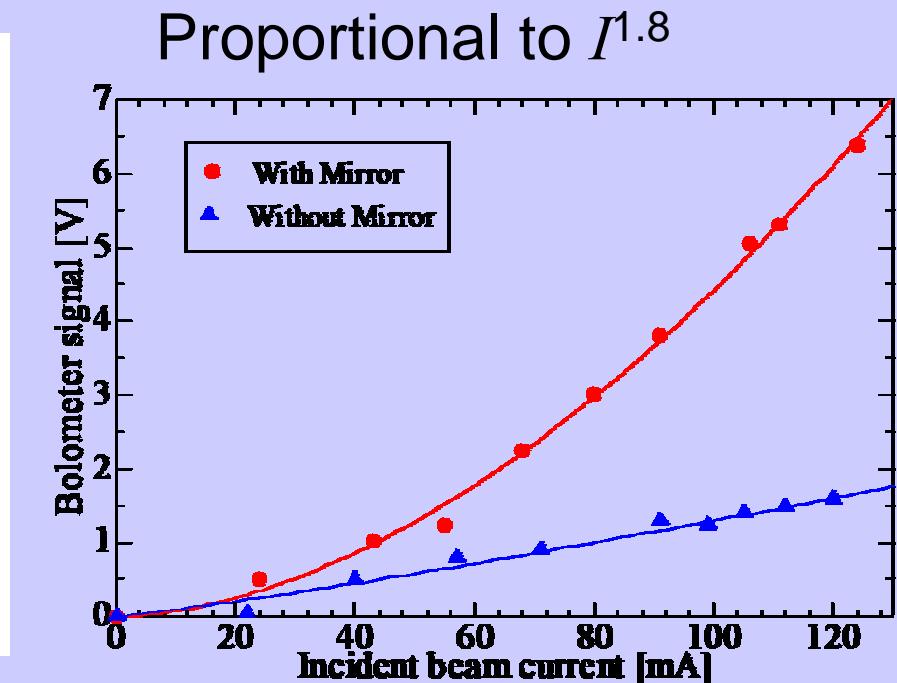
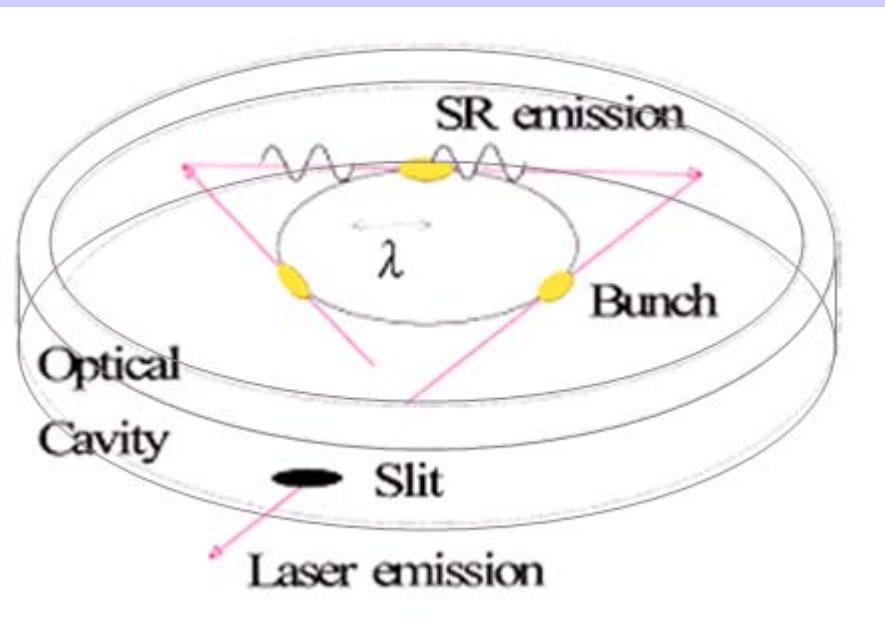
Water-acetone mixture measured by MIRRORCLE-20

Miura and Kitagawa, Synchrotron Light Life Science Center



Coexistence of hydrogen bonding of water and dipole-dipole interaction of acetone

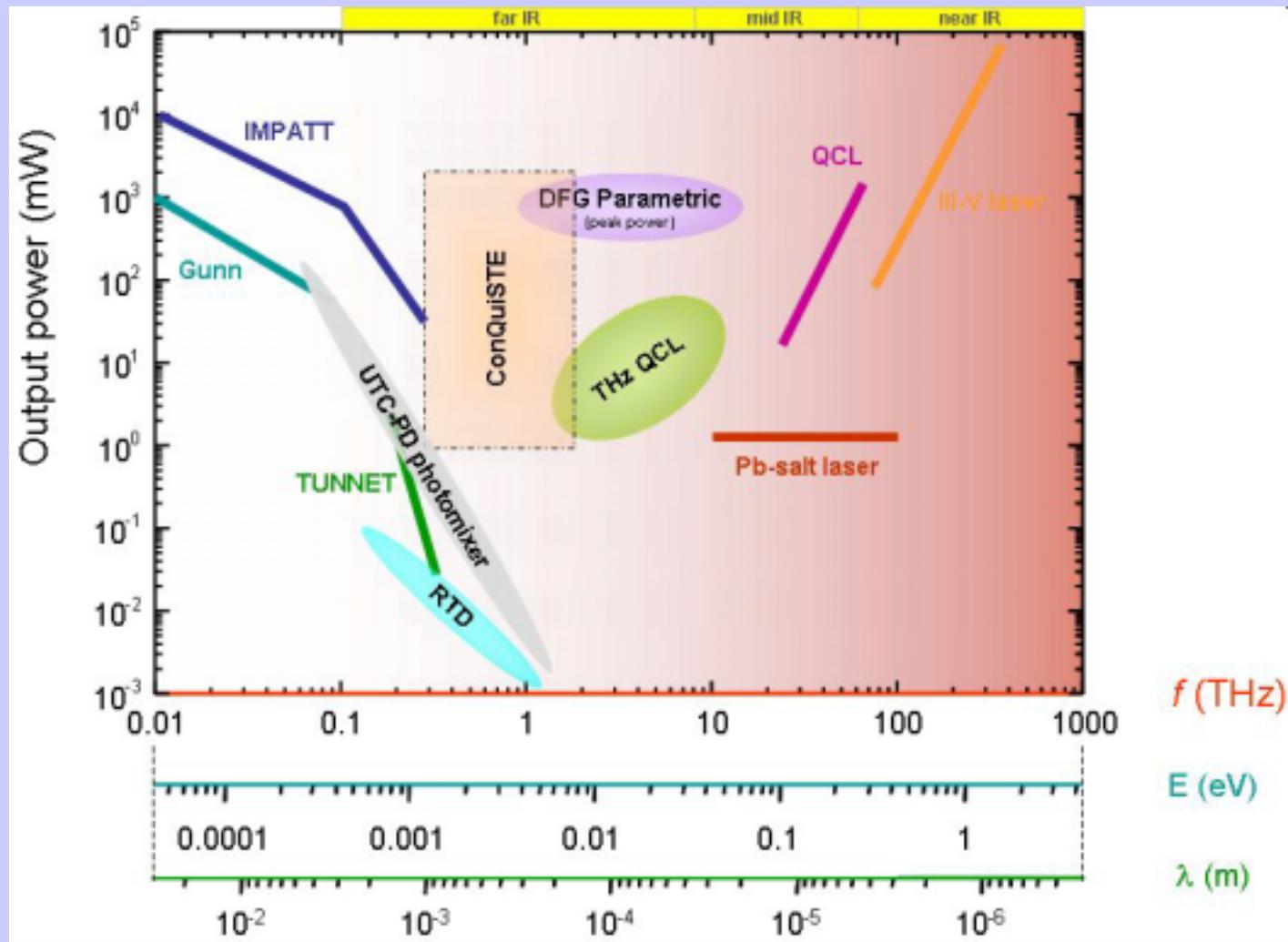
Coherence of FIR radiation



Stimulated emission appears by the interaction of the orbiting electrons and accumulated SR lights.

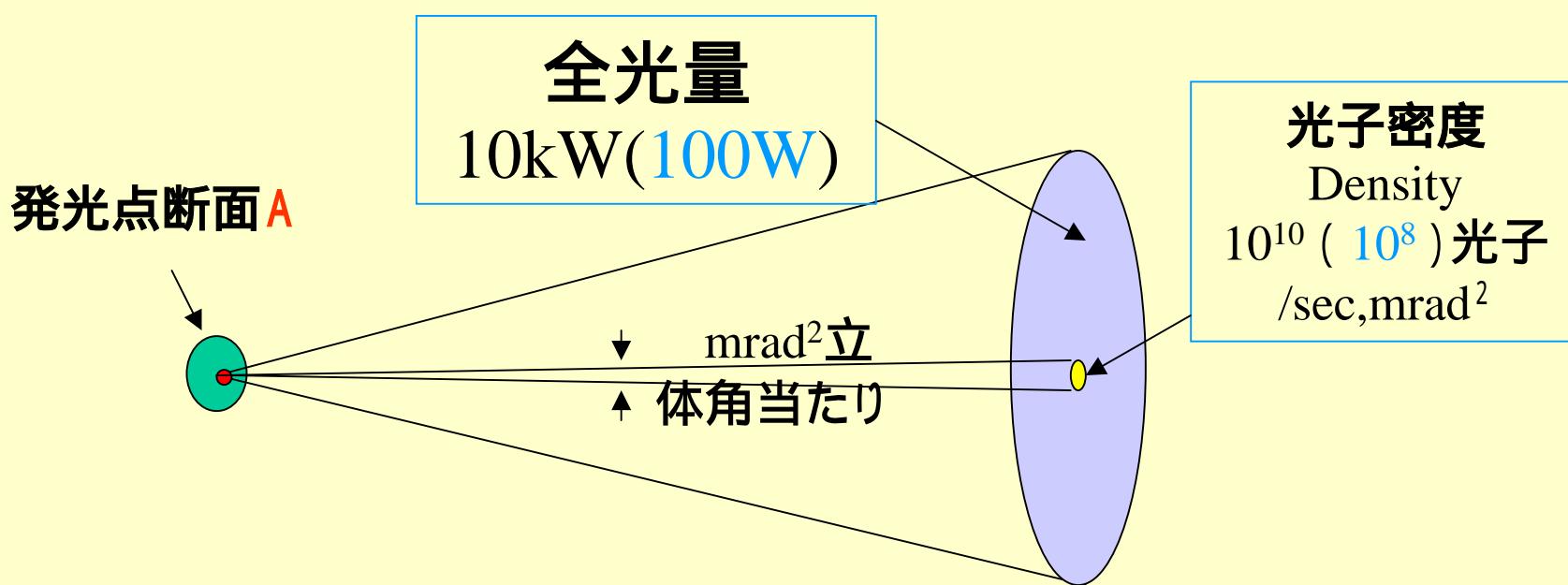
$$\lambda = 4\rho(\alpha / \beta - \sin(\alpha))$$

World status of THz sources





“みらくる”は発散角の大きな光源ですが単位面積当たりの強度が放射光並、積分強度は放射光を超える

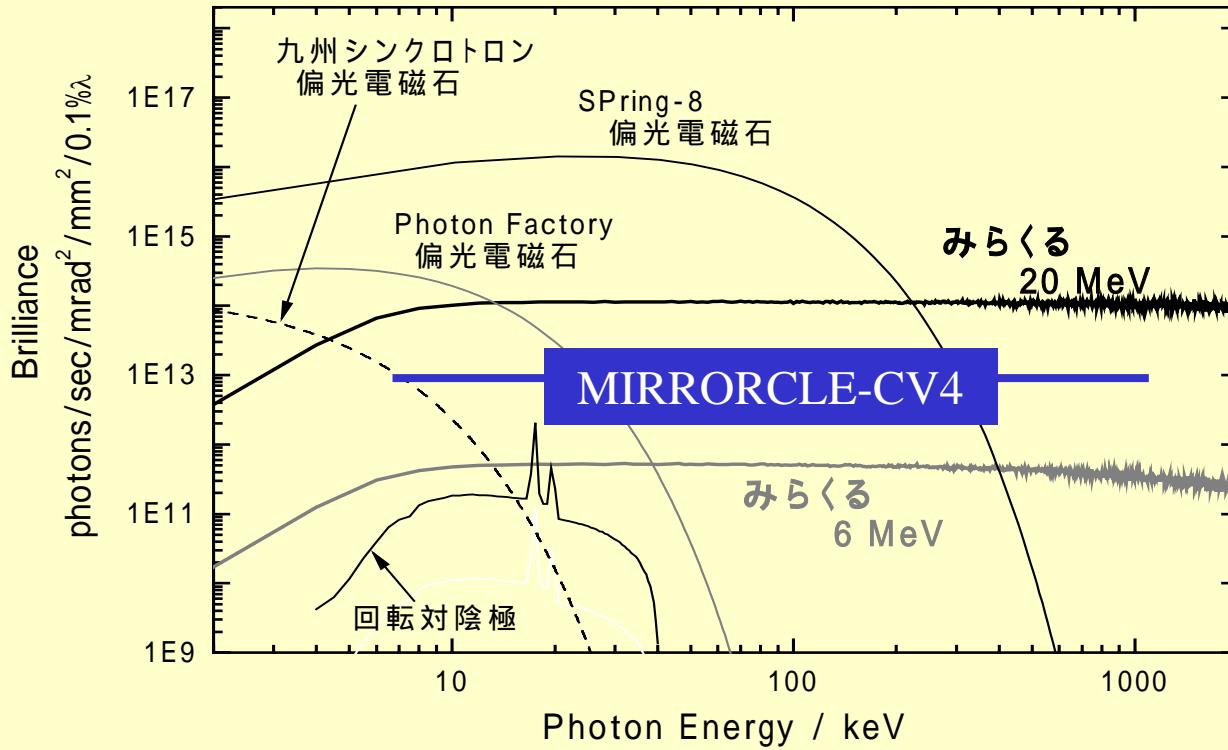


光子密度 = 光子数 / sec、単位波長当たり
発光点の大きさを考慮しない定義

輝度 Brilliance = 光子密度 / A

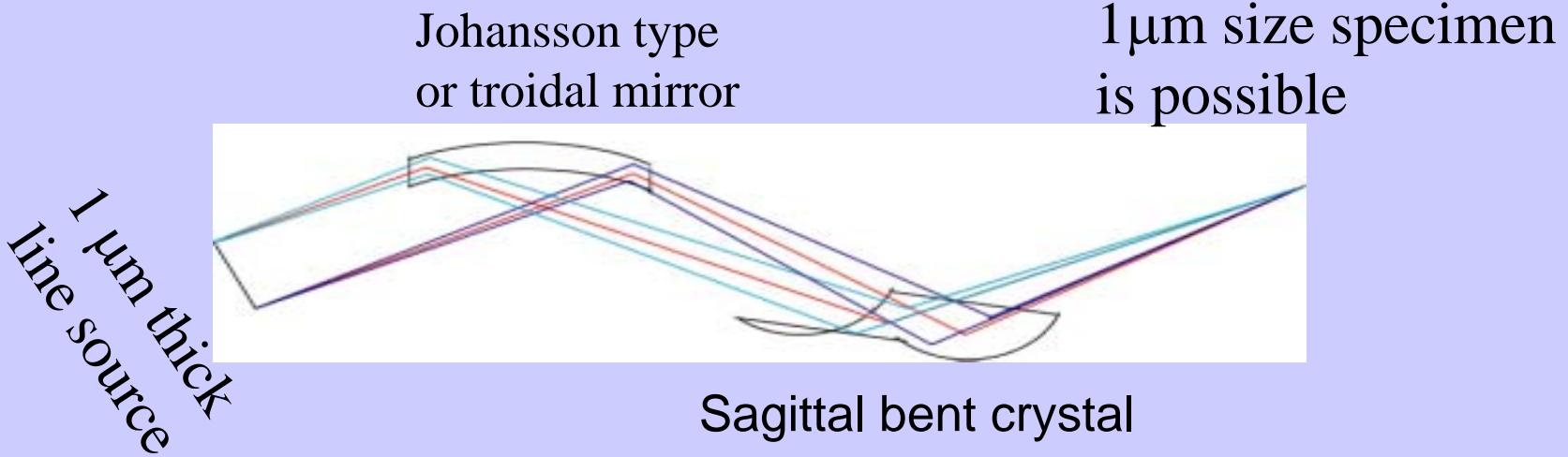
BrillianceとFlux

Brilliance



“みらくる”のX線強度は、入射器のパワーを上げればさらに上がる！

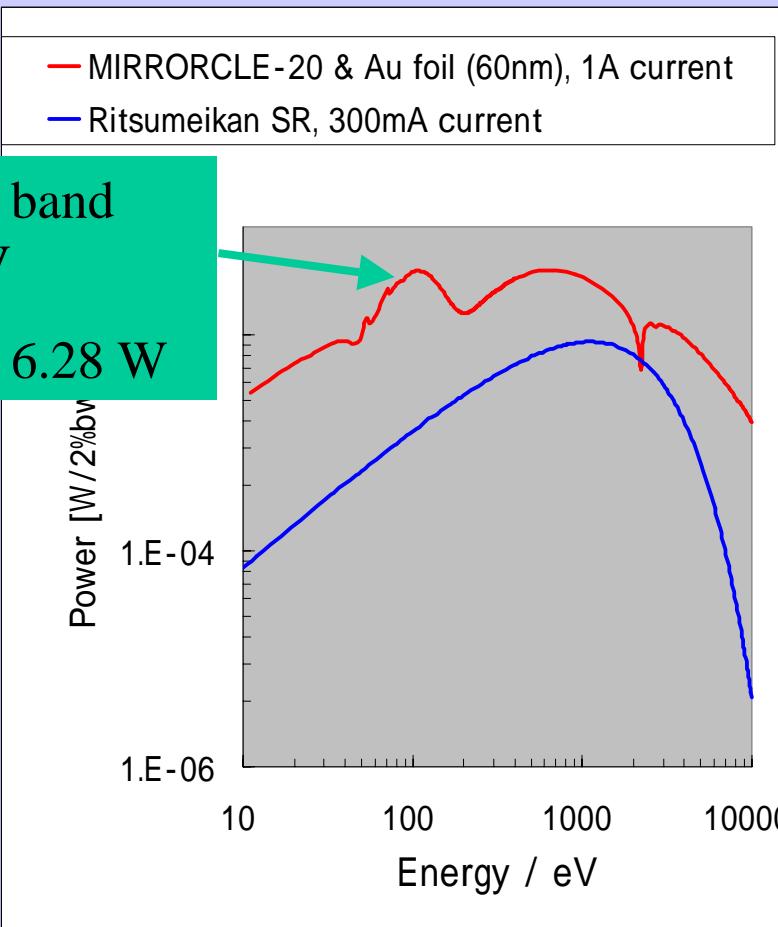
適切な光学系で容易に100倍を達成できる



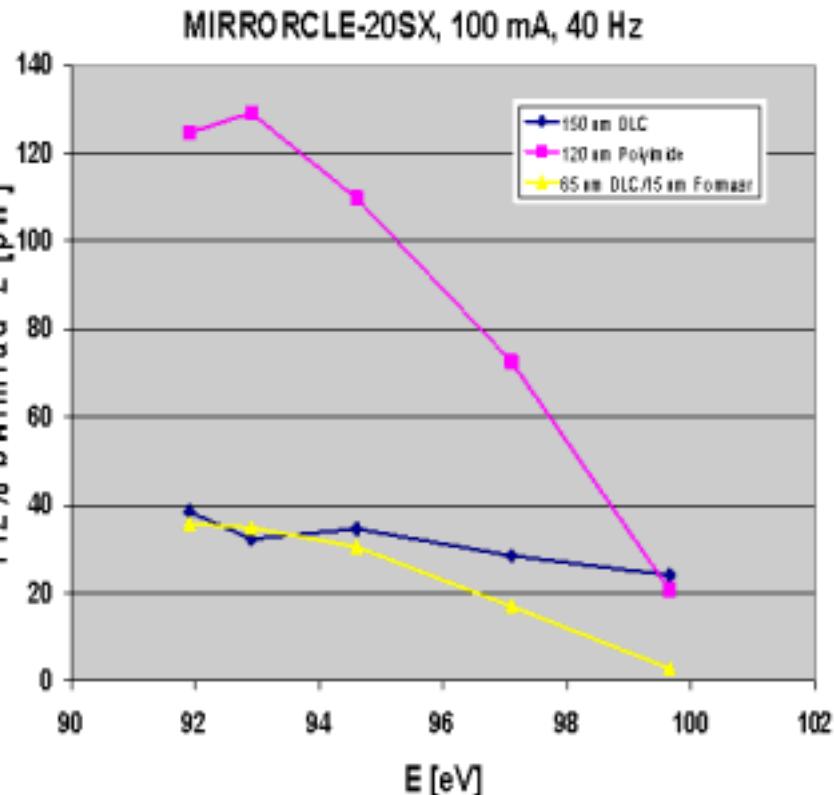
EUV ~ Soft X 線パワー



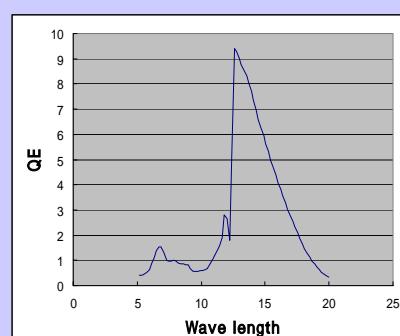
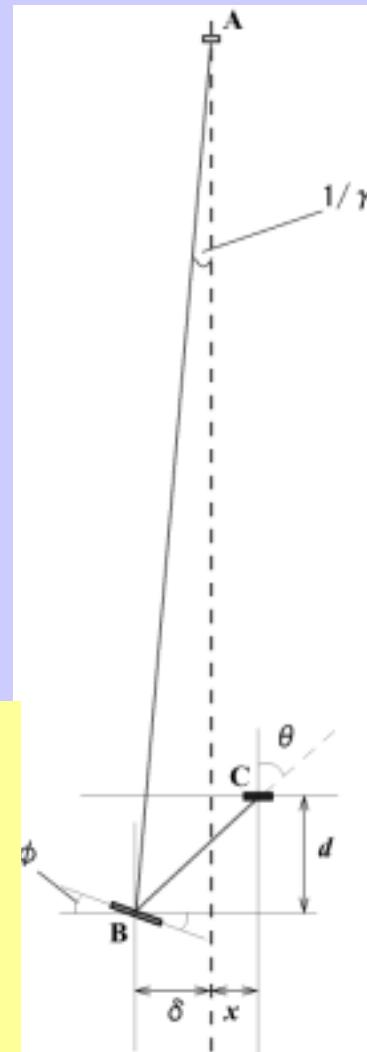
30mW/2% band width EUV
Integrated: 6.28 W



Measured spectrum at EUV region

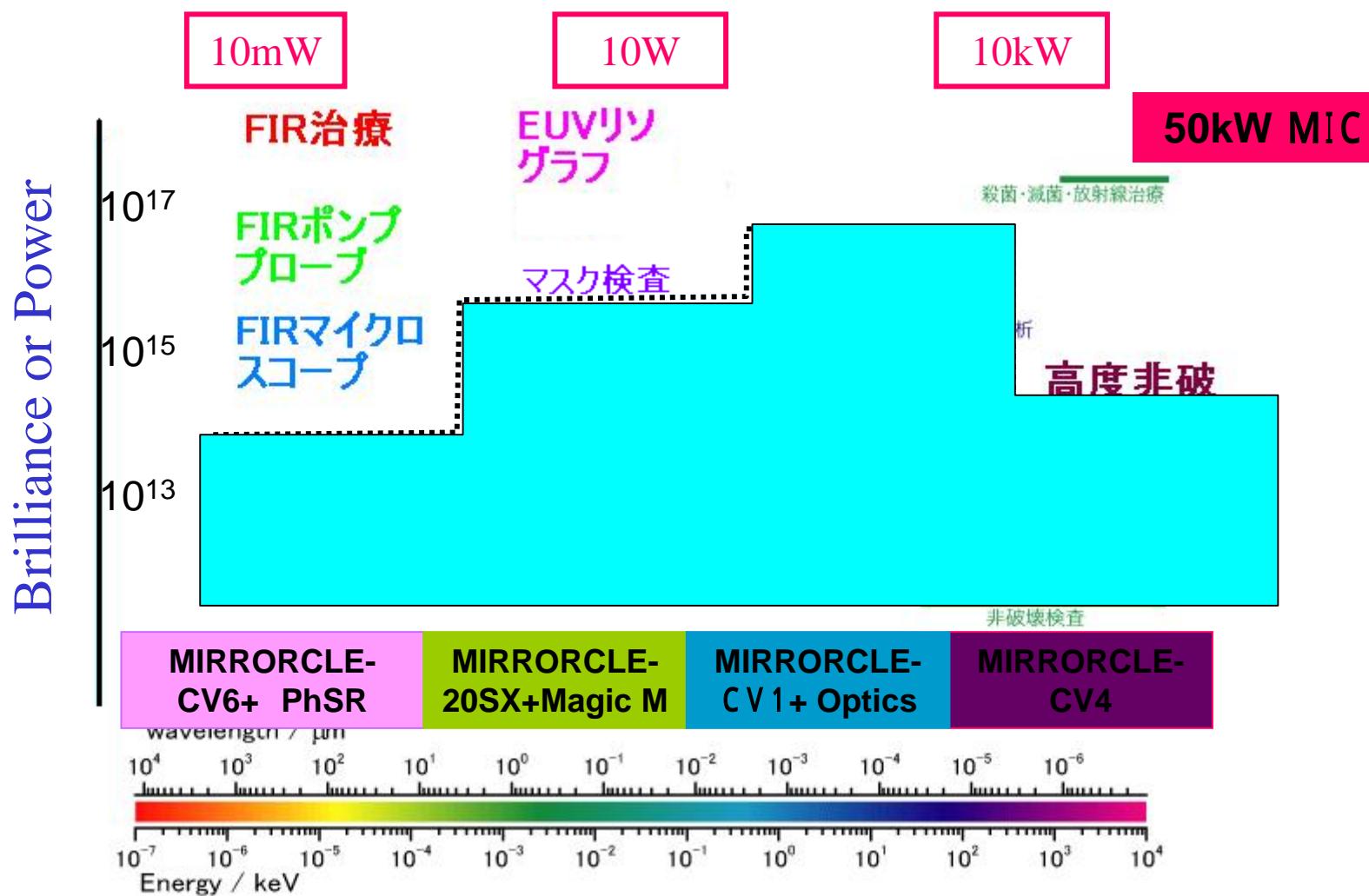


'Mo/Si multilayer mirror (50 Mo/Si bilayers with the period of 6.95 nm)
The reflection of EUV at 13.5 nm is R~0.695.

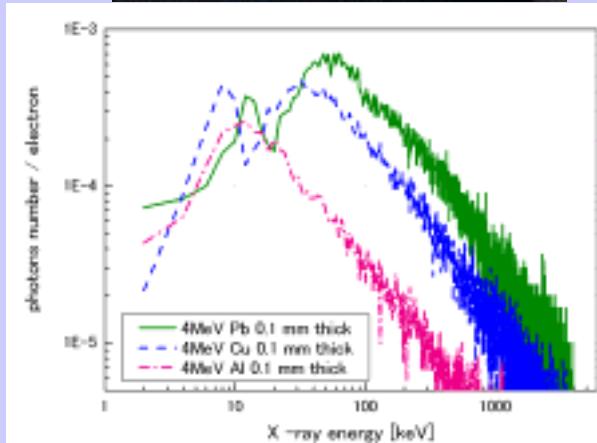
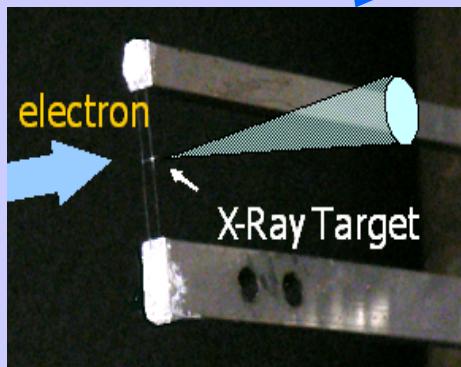
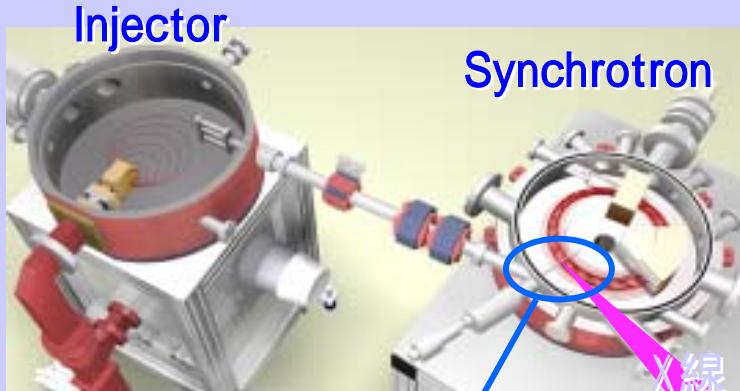


'SXUV-100Si/Zr' made by International Radiation Detectors Inc

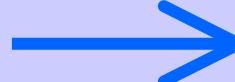
現在の“みらくる”がカバーするパワー領域



“みらくる”の特性を生かした利用分野



1. High current



Orbit radius=8cm
> portable source
stored beam current=4A
> High power radiation source

2. Small emission point

3. Cone beam

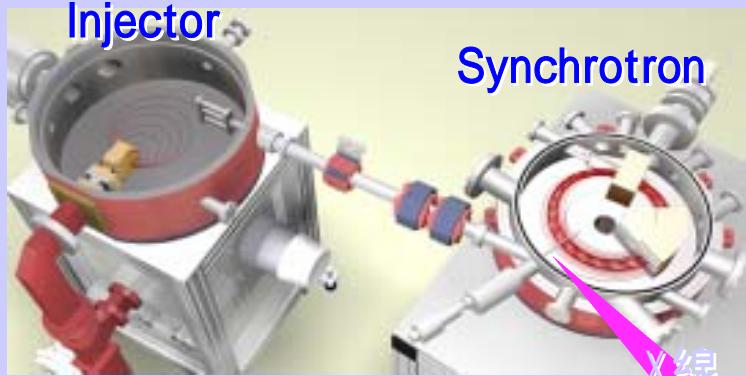
4.
Polychromatic X-ray

1-10 μm target
> Magnified imaging

> Monochromator provides high energy resolution with very short beam line

High energy X-ray
➤ NDT of heavy construction
➤ 2 color experiment by different targets
➤ X-ray energy is tunable

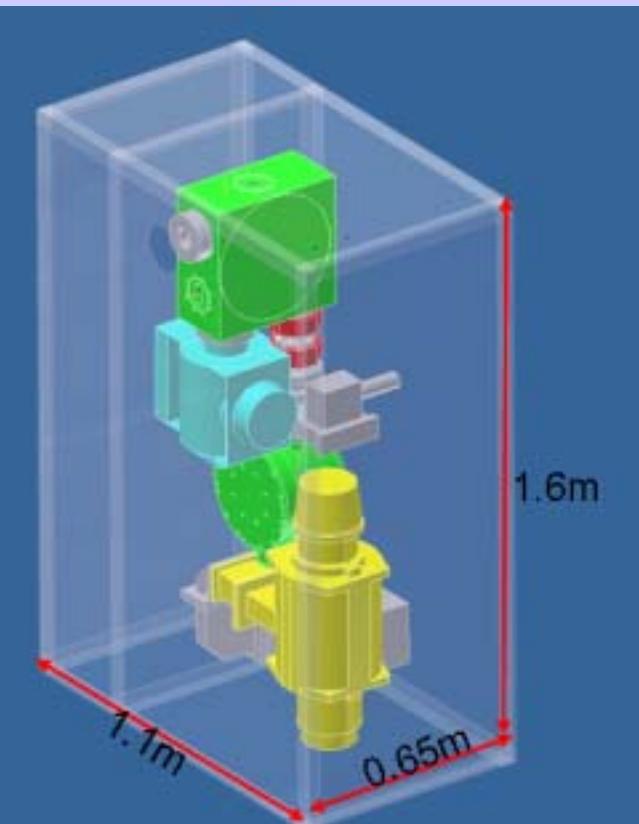
MIRRORCLE型放射光の3つの特徴 (I)



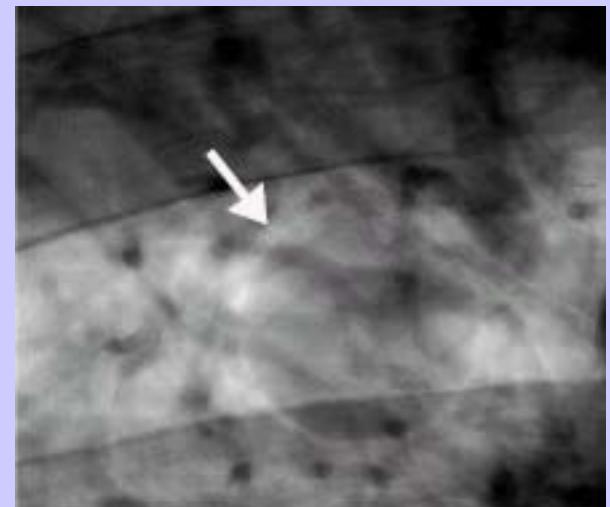
1. Small orbit radius



Orbit radius=8cm
> portable source
stored beam
current=4A
> High power radiation
source

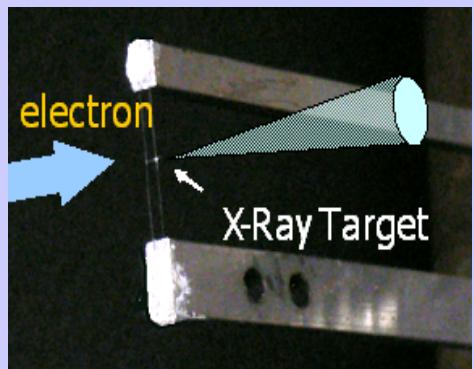


等倍



12倍拡大

MIRRORCLE型放射光の3つの特徴 ()

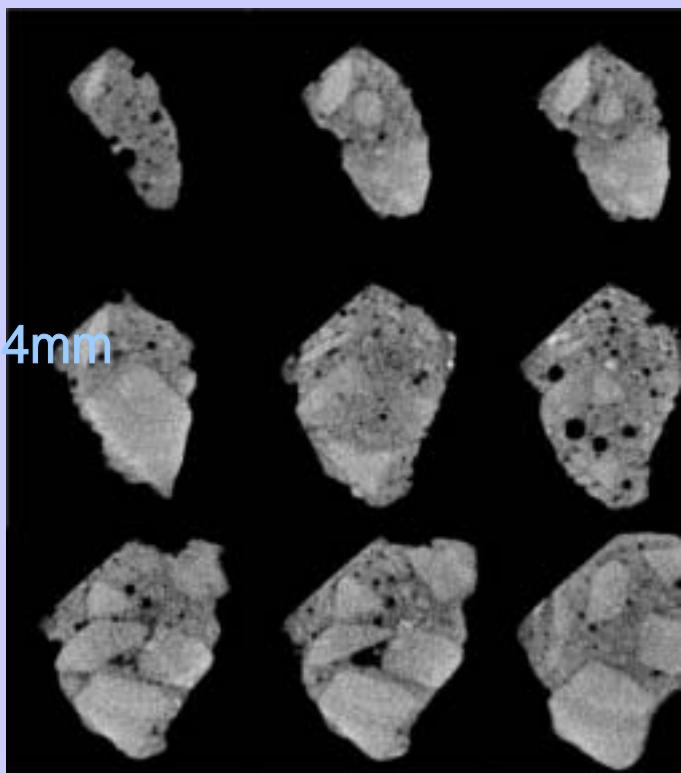
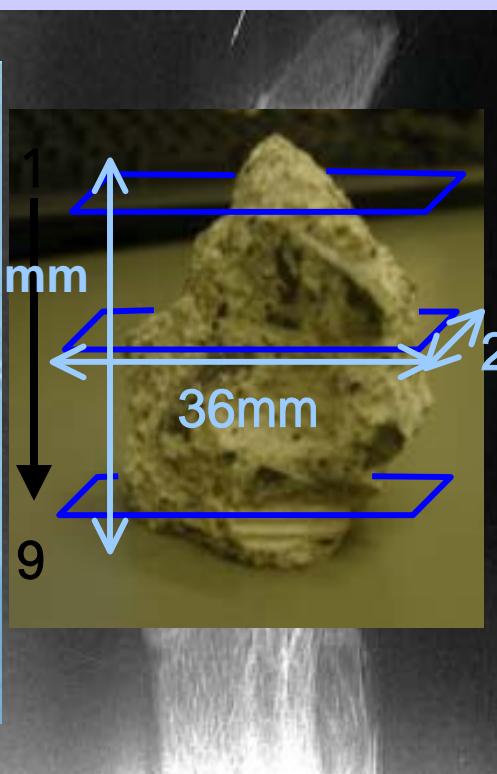
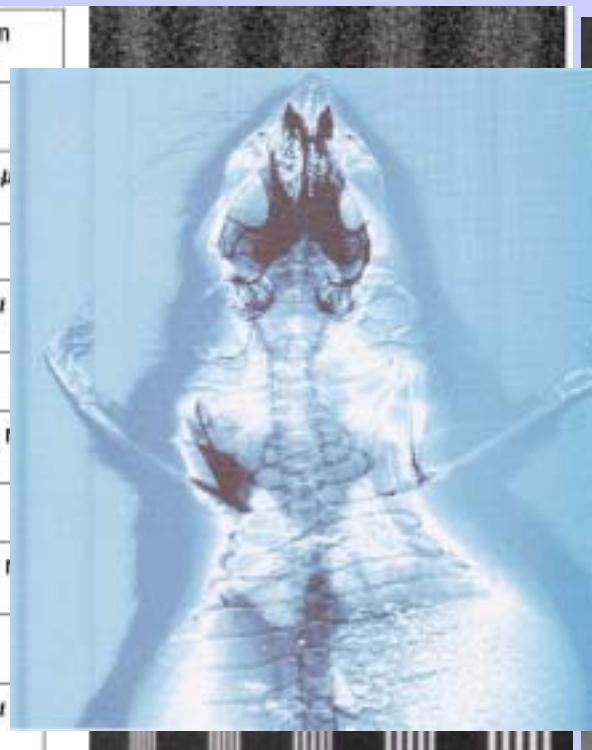


2. Small emission point

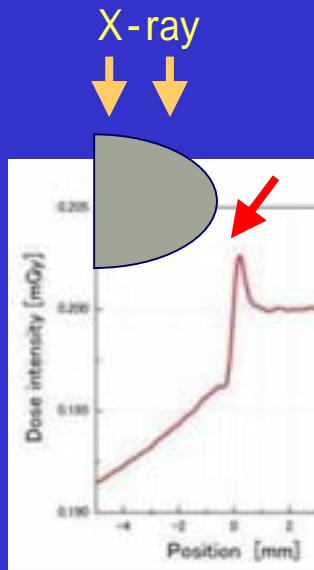
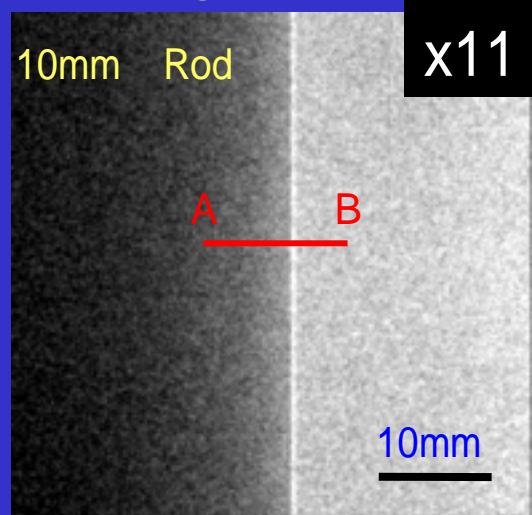
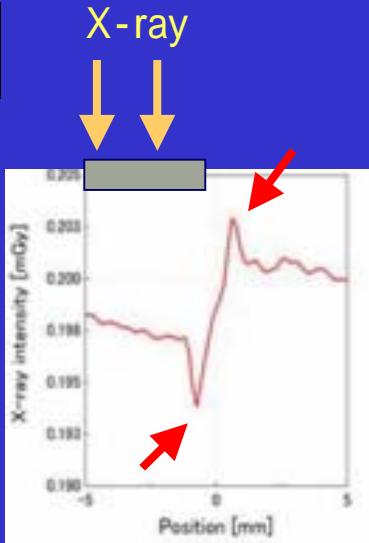
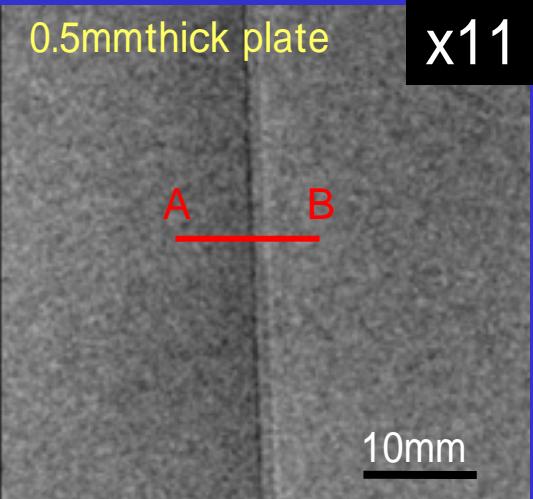
1-10 μm target

- > Magnified imaging
- > distance reduces the scattering background

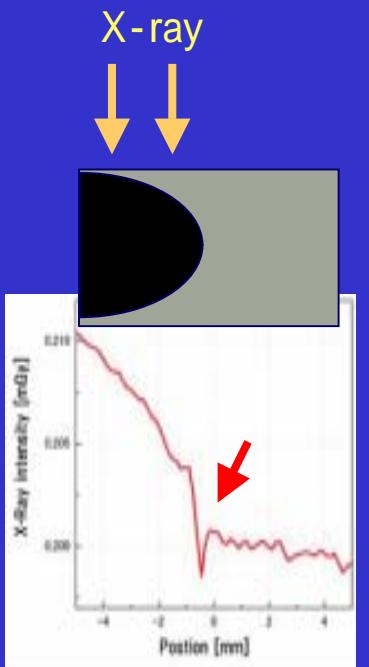
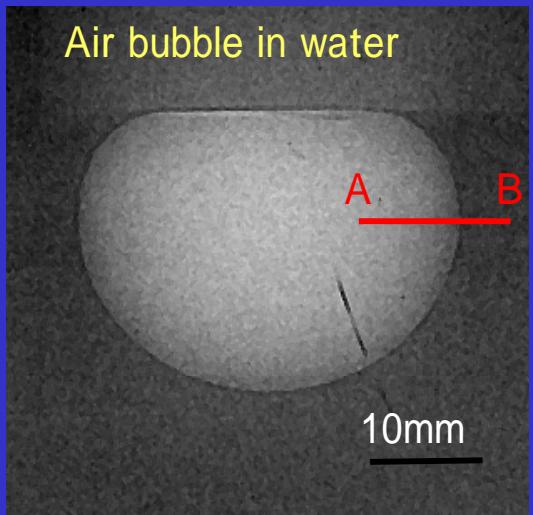
3. Cone beam



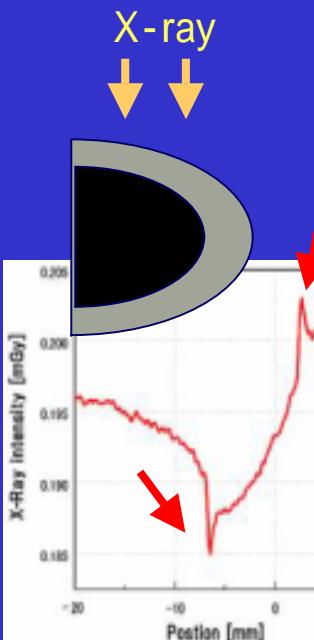
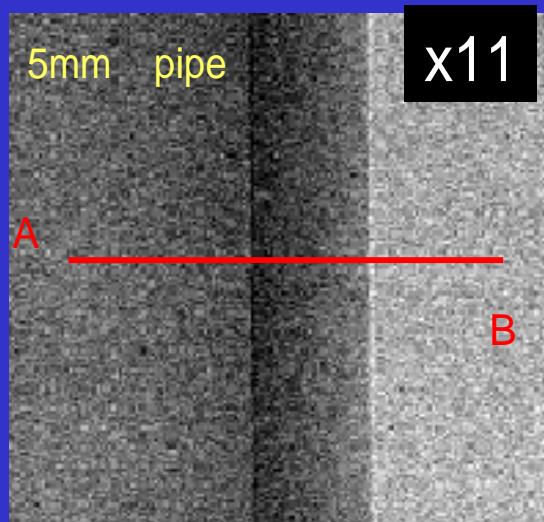
Shape dependence of edge effect



Plane sample
target: W10 μm Wire



□shape
target: W10 μm Wire



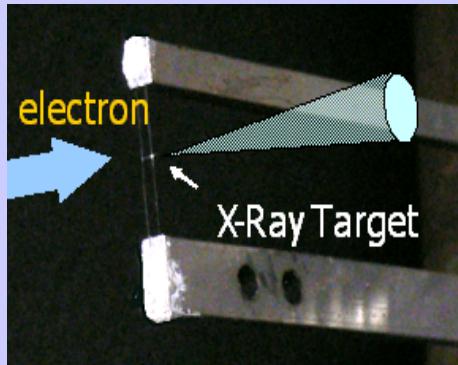
□shape

target: Cu25 μm Rod

□凸shape sample

target: W10 μm Wire

Fine energy resolution of monochromator



2. Small emission point

3. Cone beam

fine energy resolution
by short beam line

➤ Suitable for
Dispersive XAFS

$$\Delta E/E = (\sqrt{\Delta\theta^2 + \Delta\tau^2} + \frac{\Delta S}{l}) \cot\theta_B$$

Detector size : 0.1mm

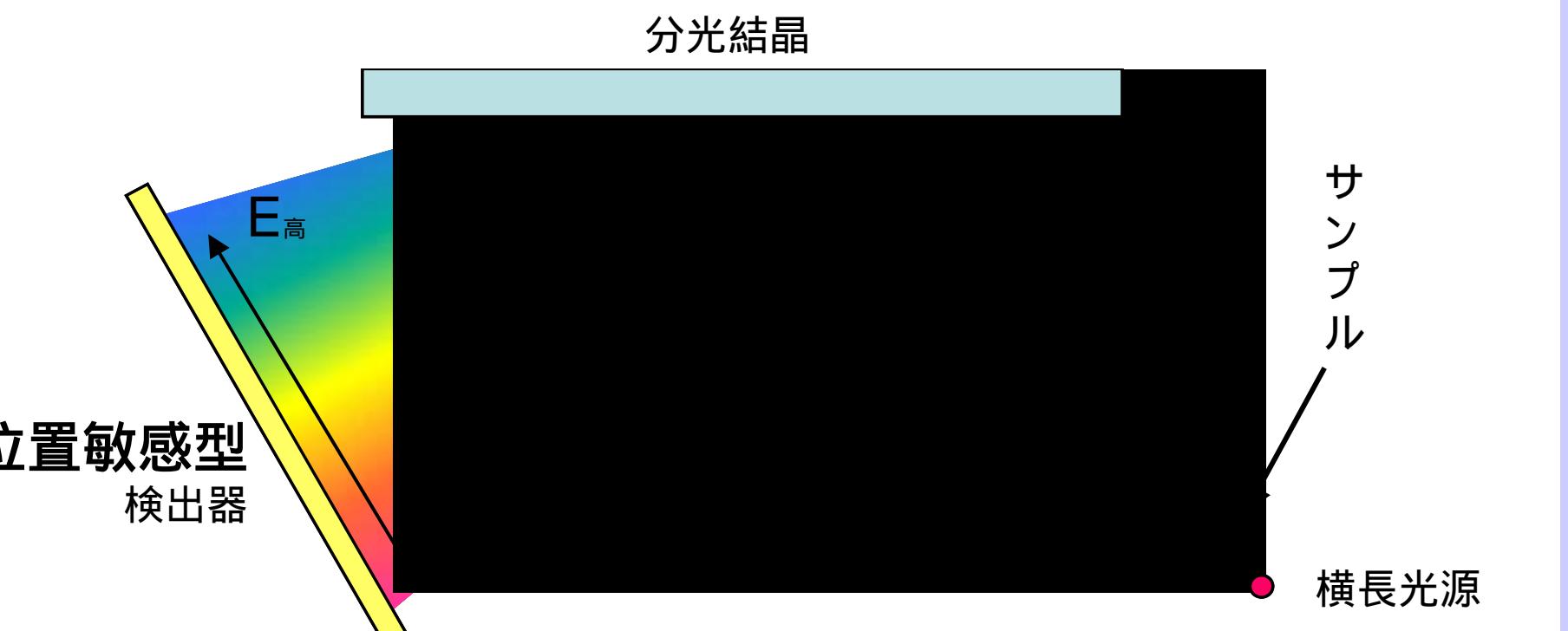
monochro:Si(111)	Source size [μ m]	Source-detector [m]	Energy resolution E/ E
Photon Factory	100	25	5000
MIRRORCLE	10	3	5000
MIRRORCLE	1	1	5100

Short beam line

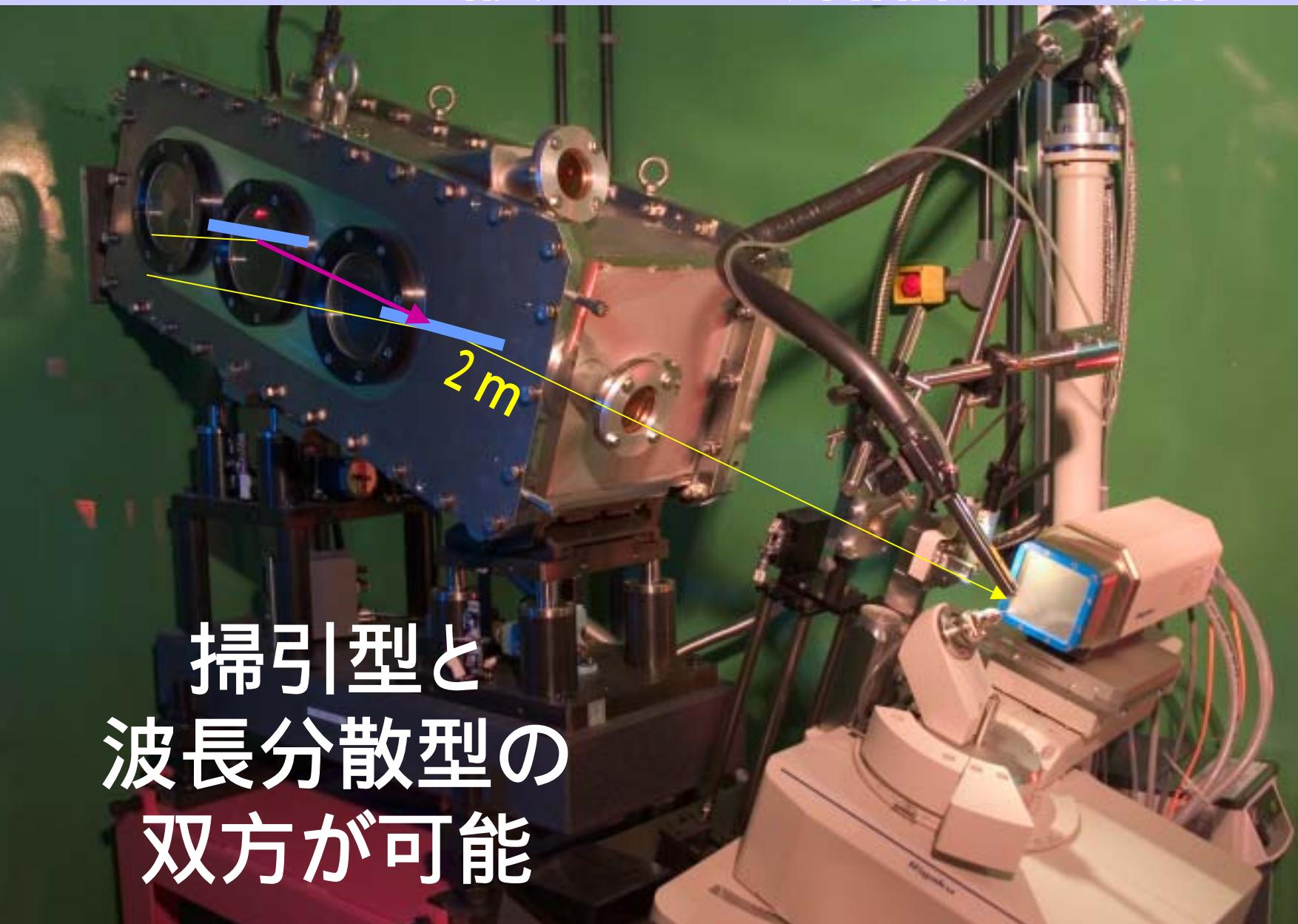
広い波長分散領域

- 目的とするXAFS領域を一度に測定する
- 測定中に動く機構がないので安定である
- 高速化が可能
- 透過法以外は困難

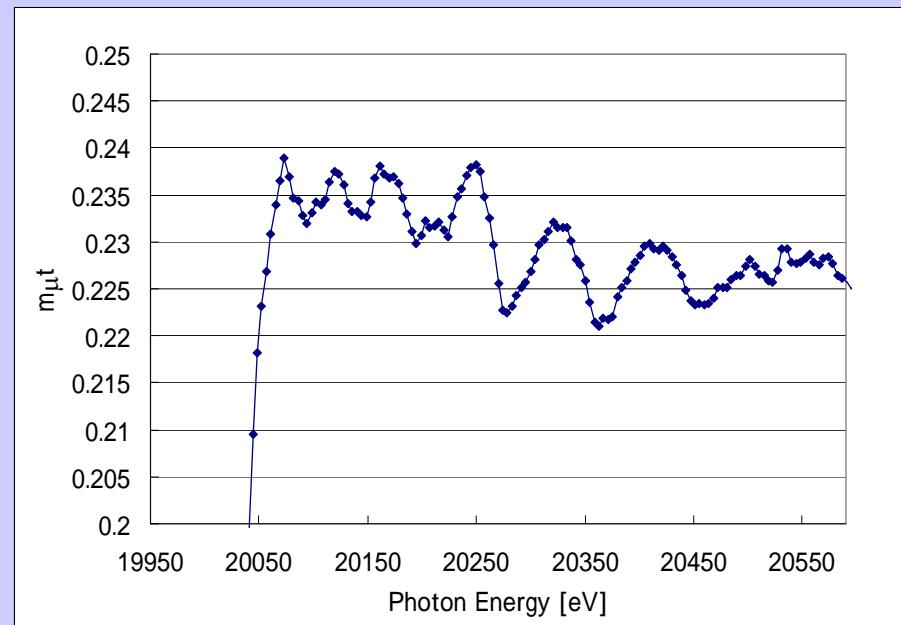
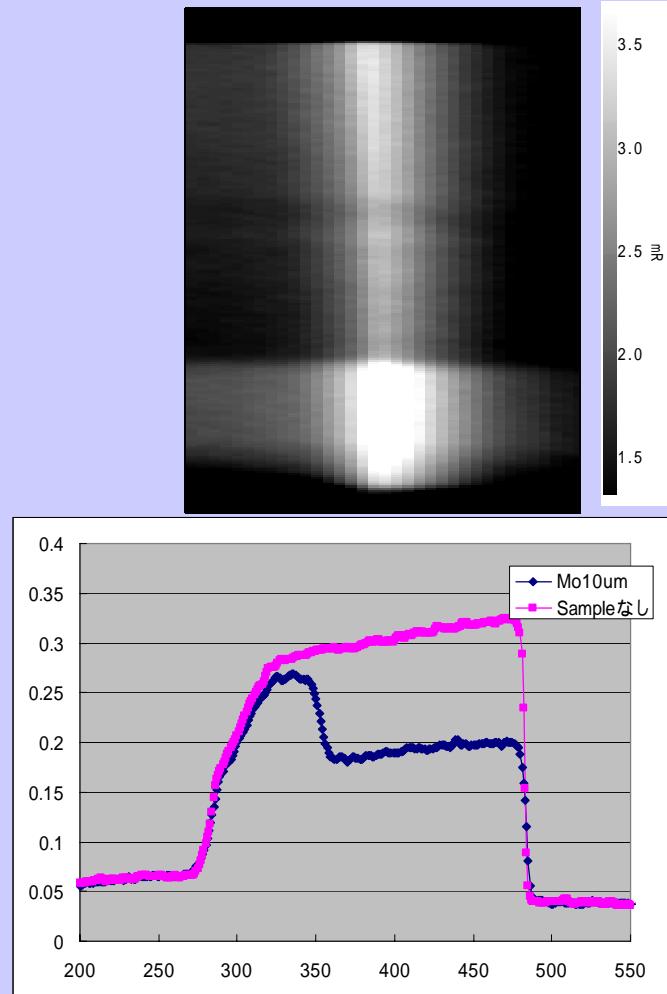
50mrad > 2keV



20SXに設置した結晶分光器



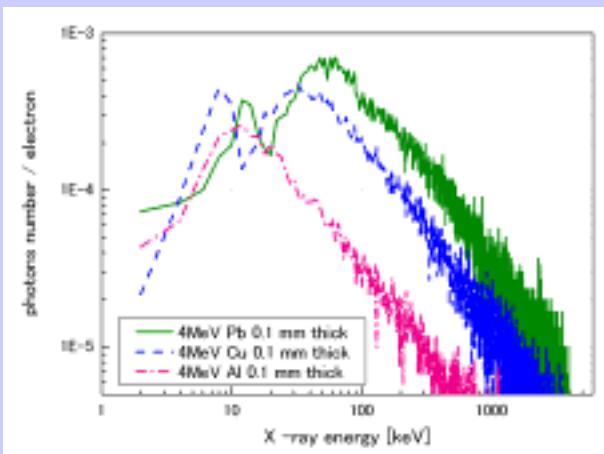
掃引型と
波長分散型の
双方が可能



- DXAFSスペクトル取得時間

1時間 > BLの短縮で6分に短縮 > 光学系の改良で3.6秒

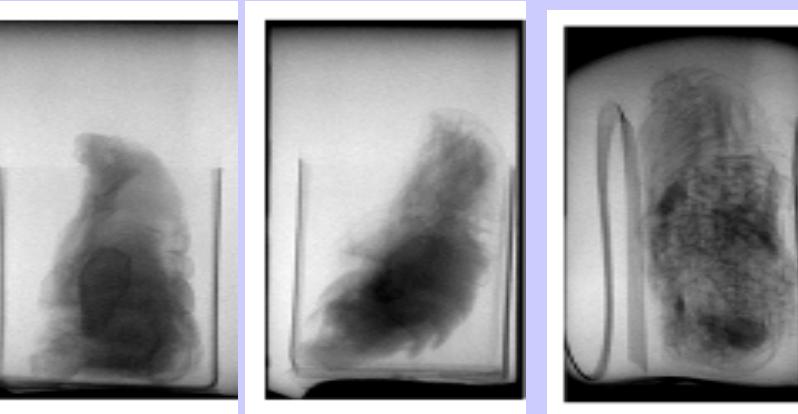
MIRRORCLE型放射光の3つの特徴 ()



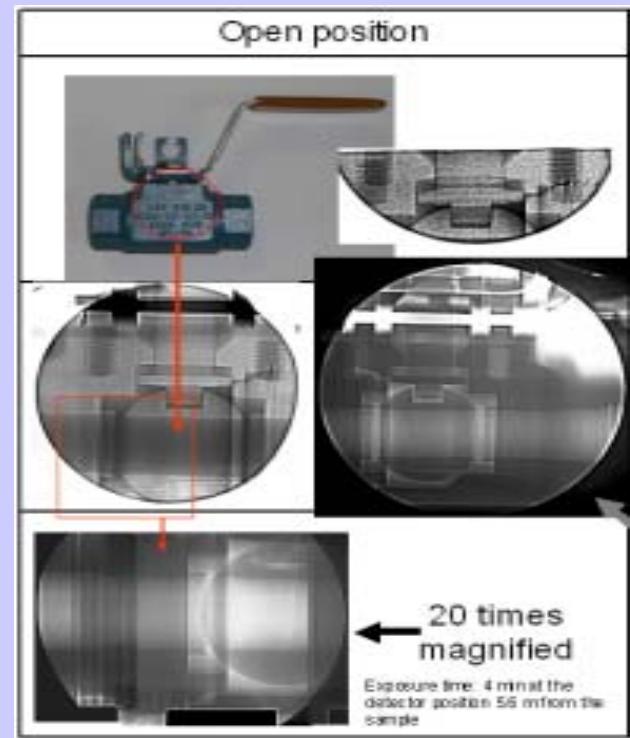
4. Polychromatic X-ray



High energy X-ray beam
> NDT of heavy construction
> Multi color experiment



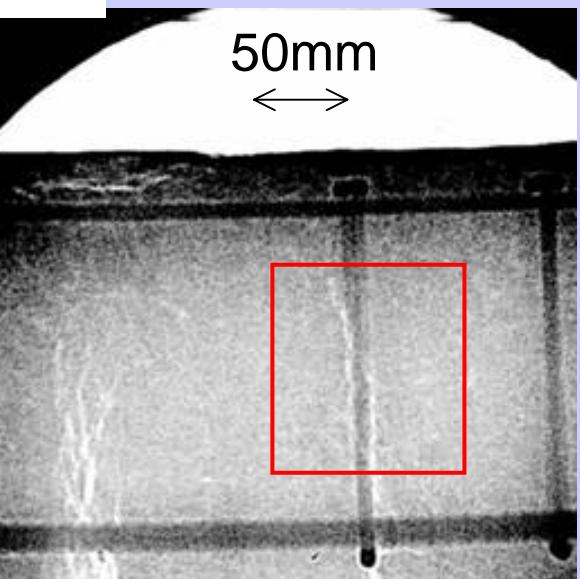
蚕のさなぎ



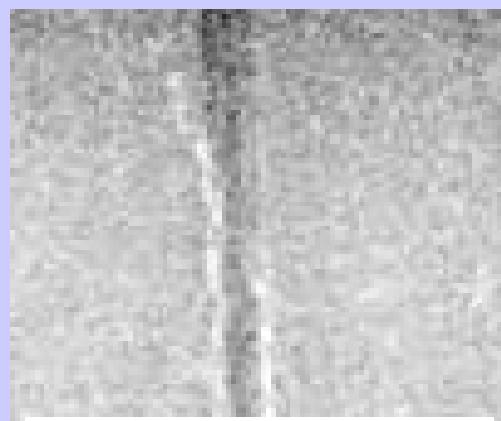
inspection of concrete

25 μ m target source-object distance
1.3m 500sec imaging time

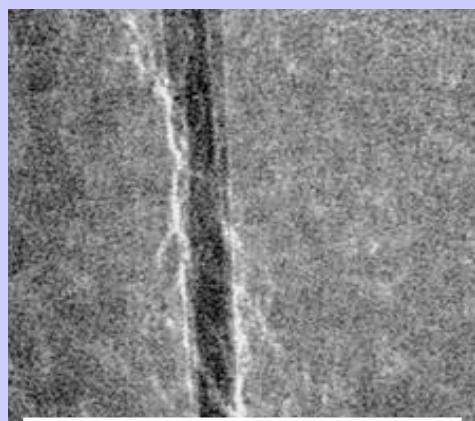
X1



5cm thick

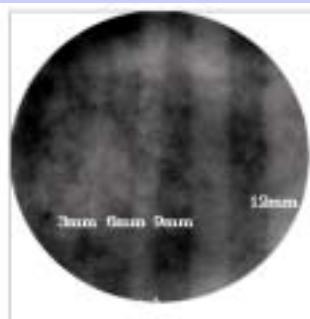
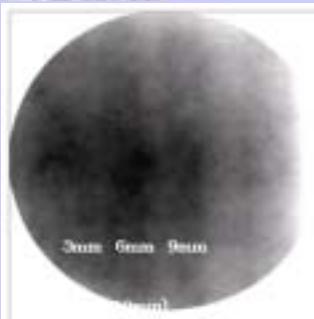


Expanded

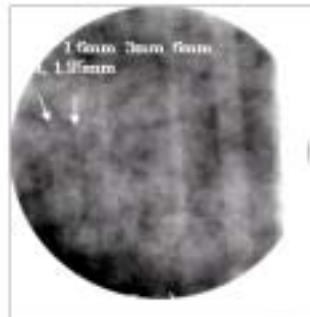
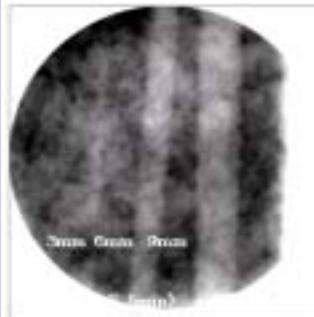


X3 projection

60cm thick
concrete

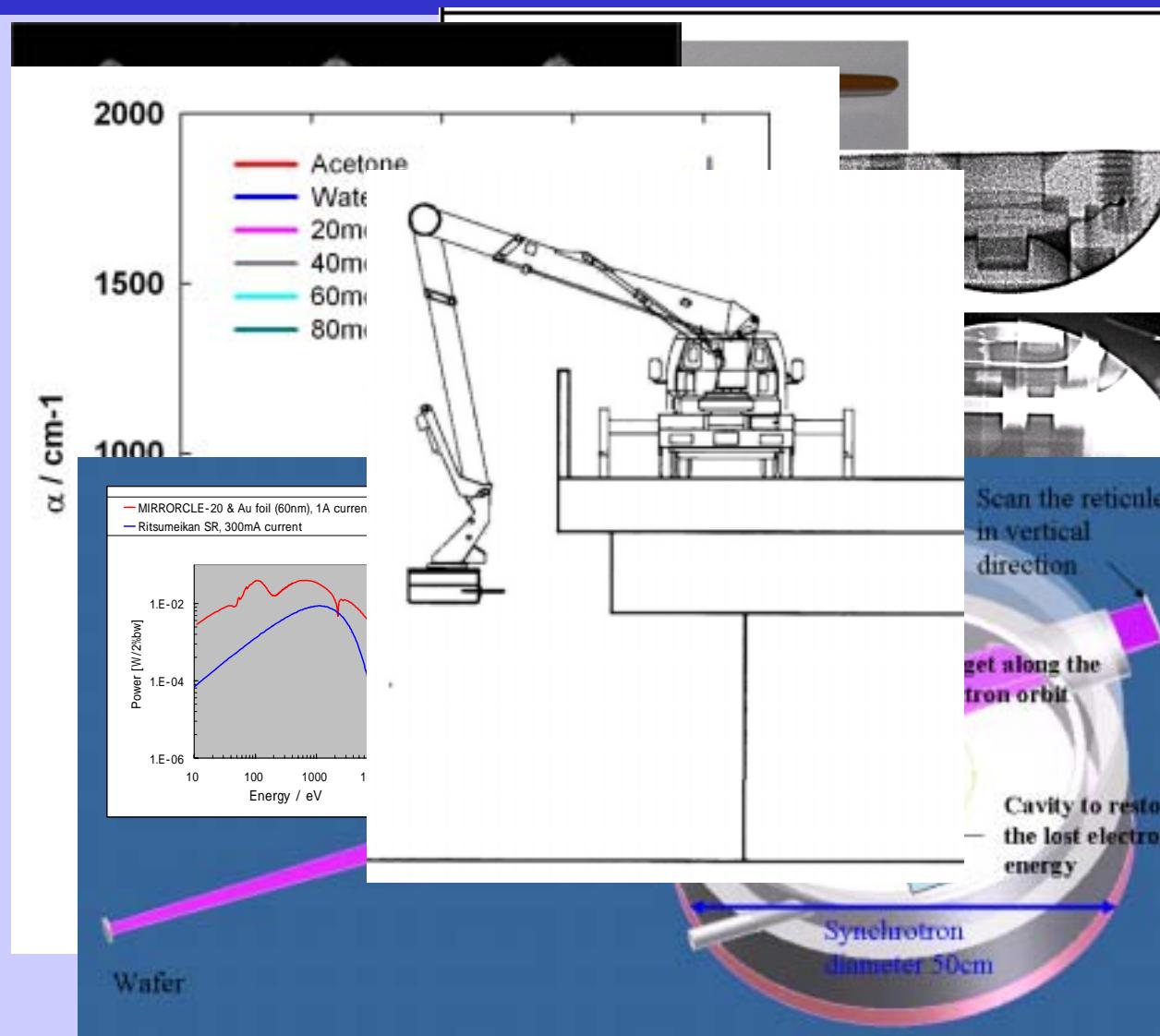


45cm thick
concrete



“みらくる”で無ければ出来ない事！

1. 見えない物が見える > “みらくる”でなければ見ることが出来ない。
2. 短時間で見える
3. 大パワーを必要とする
4. 小型・経済的である



“みらくる” 利用分野

微細X線画像装置

サブミクロンからナノ領域に
おけるX線顕微CT装置

X線医療 診断・治療装置

原子炉、石油プラント
の配管、建家検査

橋梁の欠陥・寿命診
断

建物の欠陥検査

コンテナーのセキュリ
ティーチェック

高度X線分析

研究機関向け科学機器
XRD, SAXS, XAFS

X線非破壊検査

コンクリートや鋼製構造物
を1mmの精度で診断

テラヘルツ 分光装置