

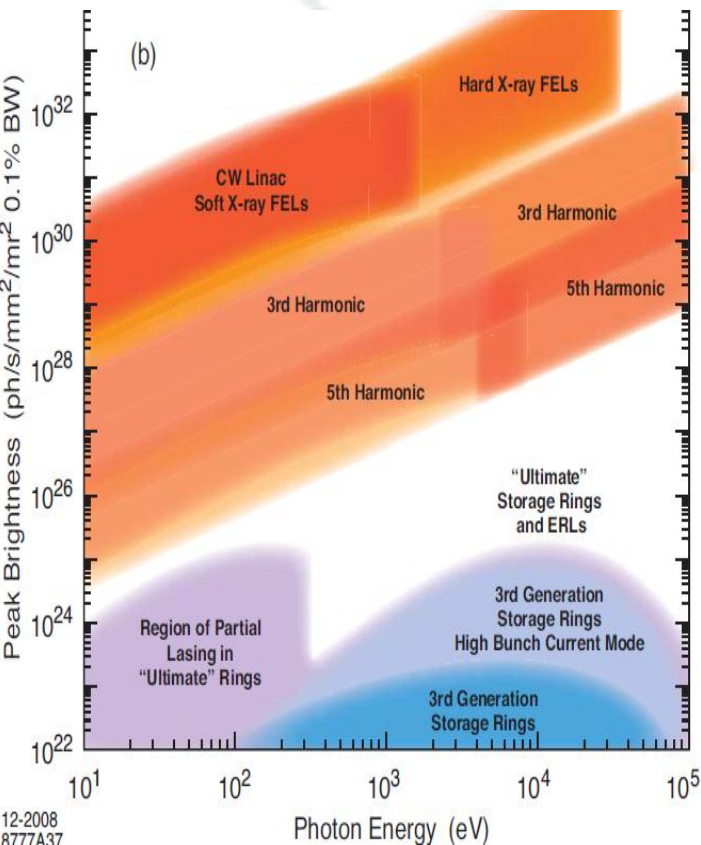
What is the “ideal” x-ray source?

Chi-Chang Kao
(Joel Brock and Jerry Hasting)

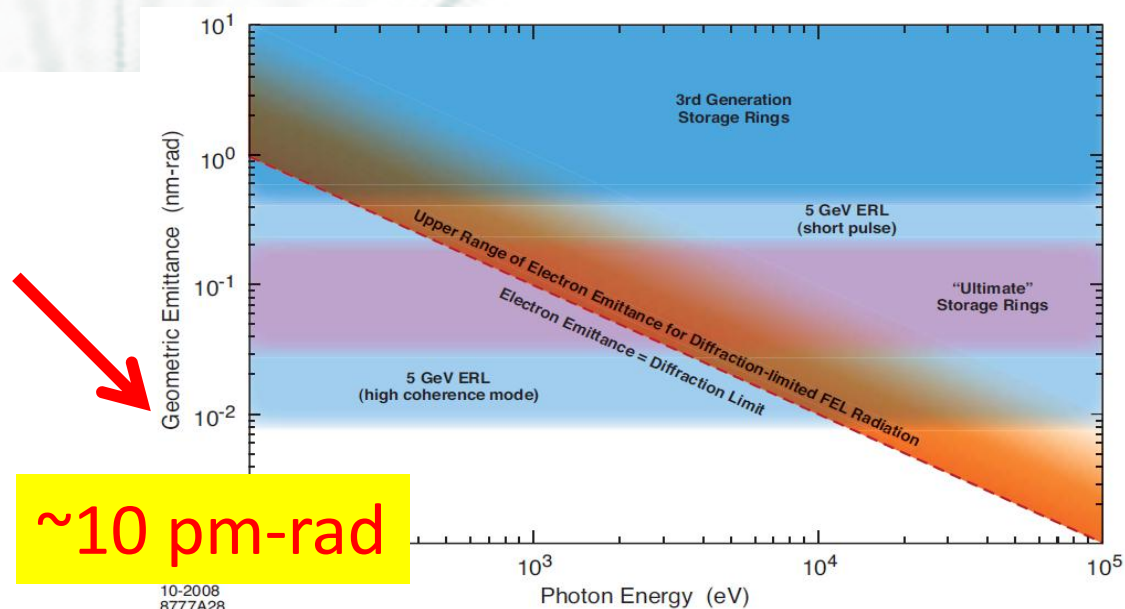
What is the “ideal” x-ray source?

- The ideal source for a specific problem?
- The ideal source that will meet the needs of everyone?
- The ideal source that could be built?

Science and Technology of Future Light Sources



A White Paper (December 2008)



X-ray FELs: National and International Context

- LCLS is the first hard x-ray FEL; LCLS-II will be built in the next six years
- NGLS has CD-0 and is making plans for CD-1
- Other US DOE FEL initiatives are developing (JLab, ANL, LANL)
- Many XFEL projects on the international stage: **SPring8**, FERMI, PSI, FLASH and FLASH-II, European XFEL, Pohang, Shanghai...
- ***LCLS works extremely well, having benefited from accelerator developments from the HEP era, but its performance could be significantly enhanced with R&D in several technology areas***
- NGLS performance will benefit in its initial operation by R&D for some key components (i.e. high-rep gun, beam spreaders, etc)
- **R&D is needed to realize the full scientific potential of present and future X-ray FEL sources and for the US to remain at the forefront of FEL science and technology**

Hard x-ray Bio-Diffraction

Spokesperson:

Sebastien Boutet, LCLS

Samples:

Petra Fromme ASU

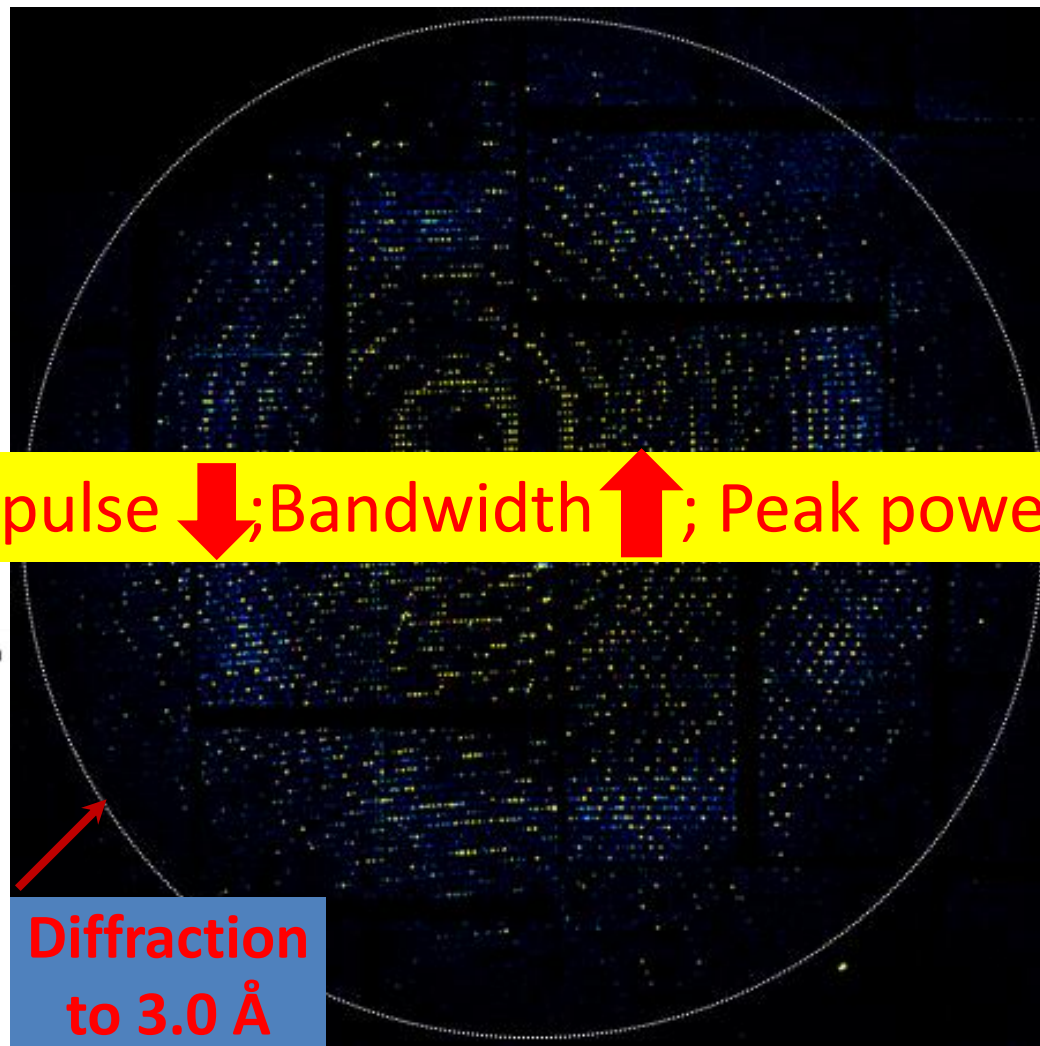
9.3 keV (1.3 Å wavelength)

Single shot:

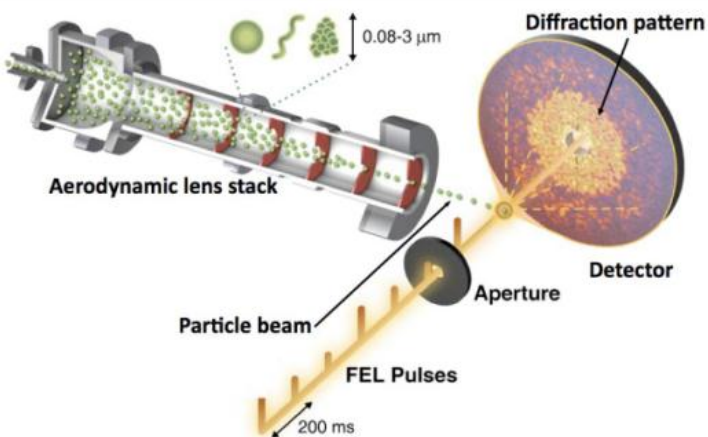
1 mJ pulse (5×10^{11} photons)

40 fs duration

Short pulse ↓; Bandwidth ↑; Peak power ↑



**Diffraction
to 3.0 Å**

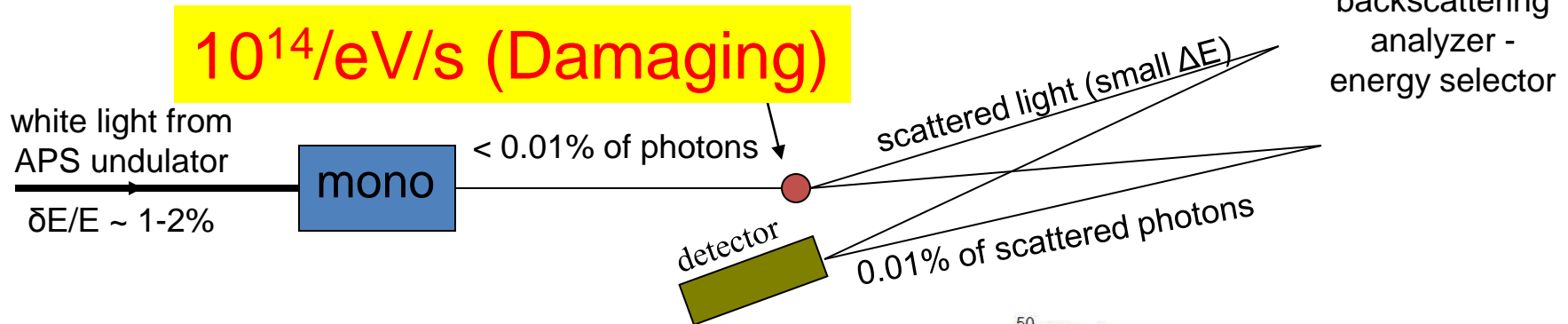


Other studied nanocrystals diffract to 1.9 Å

Inelastic x-ray scattering – why it's so hard (Finkelstein, IXS 2010)

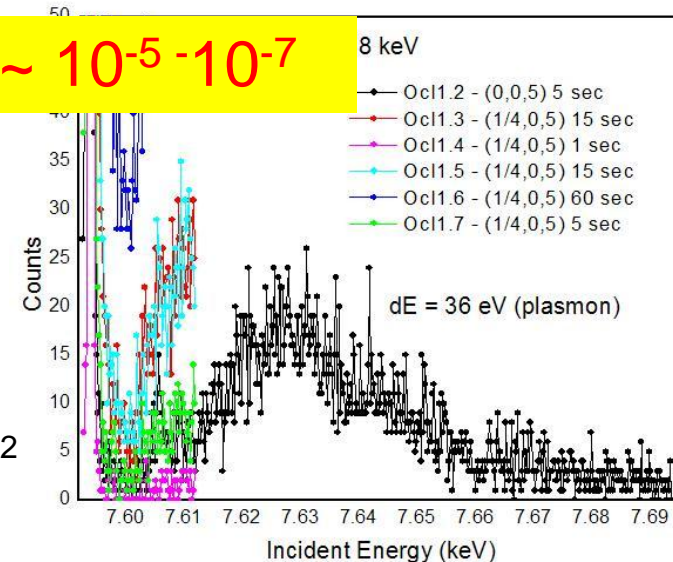
IXS measures $S(\mathbf{k}, \omega)$, i.e. the charge response.

1. X-ray diffraction is coherent, scales like N^2
2. IXS incoherent, scales like $N_{\text{valence}} \sim 0.1 e \ll N$
3. Mono and analyzer throw away 99.9999% of the photons

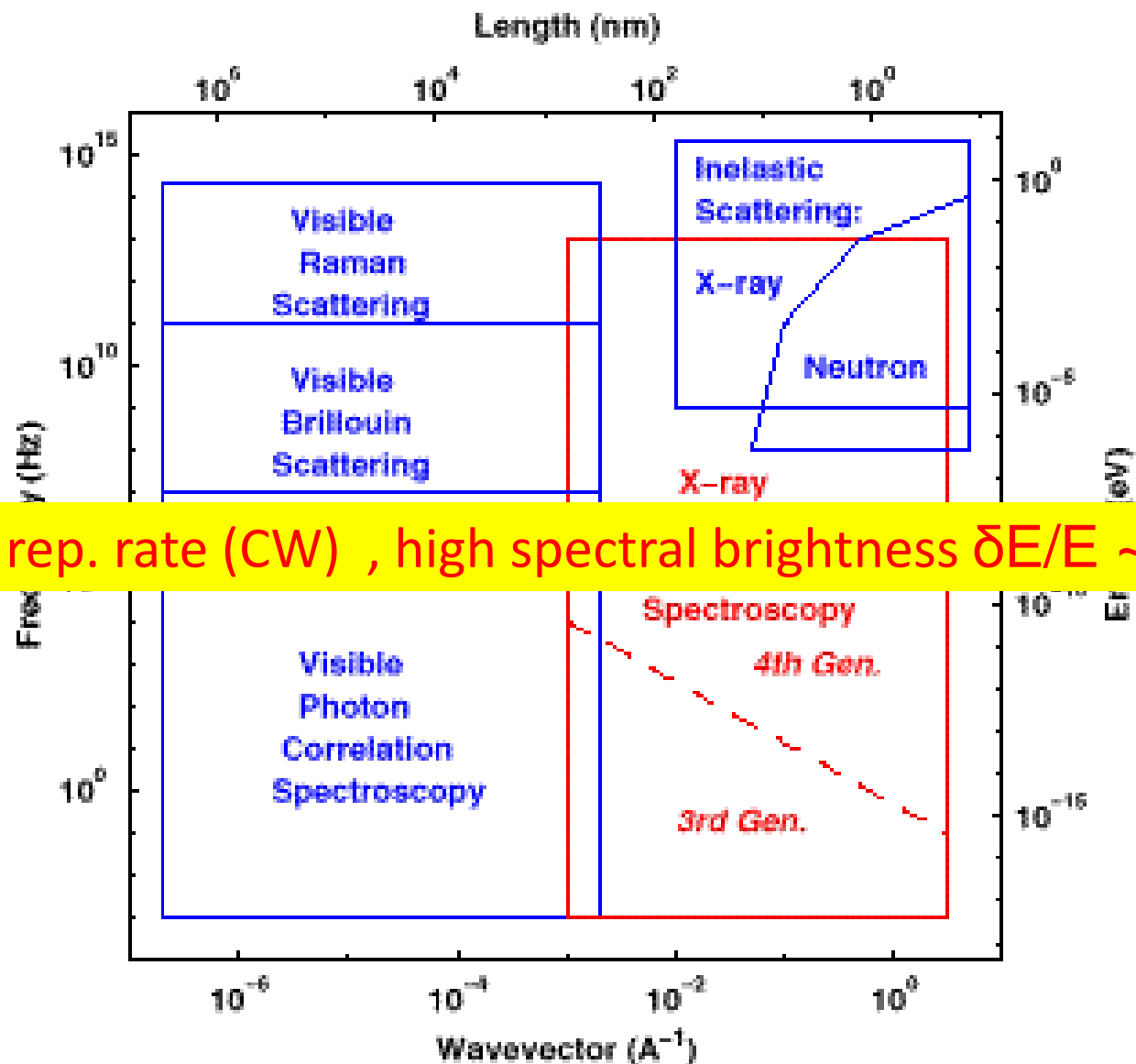


High rep. rate , high spectral brightness $\delta E/E \sim 10^{-5} - 10^{-7}$

Upshot: Signal is weak and sitting on tail of elastic, which is stronger by N^2/N_{valence}



X-ray Photon Correlation Spectroscopy



High rep. rate (CW) , high spectral brightness $\delta E/E \sim 10^{-4}$

X-ray FEL Performance: Present and Future

Parameter	Now	Future
Photon energy (keV)	Up to 10	Up to 100
Pulse repetition rate (Hz)	≤ 120	10 ² - ≥10⁶
Pulse duration (fs)	~2-300	<1-1000
Coherence, transverse	diffraction limited	diffraction limited
Coherence, longitudinal	not transform limited	transform limited**
Coherent photons/pulse	2x10 ¹² -3x10 ¹³	10 ⁹ - 10¹⁴
Peak brightness (usual units [†])	10 ³³	10 ³⁰ - 10³⁴
Peak/average power (W)	7x10 ¹⁰ /~1	> 10¹²/≥10³
Average brightness (usual units [†])	4x10 ²²	10 ¹⁸ - 10²⁷
Polarization	linear	variable, linear to circular
Stability – intensity/energy RMS	3-15%	< 3%
Stability – time (fs) RMS	50	< 5
Stability – % mode size	10%	< 10%

[†]photons/s/mm²/mrad²/0.1% BW

$$* \Delta t \cdot \Delta E_{\text{ph}} = \frac{h}{4\pi} \quad (\text{Gaussian pulse})$$

Summary

- Identify problems that can capture the imagination of many
- Organize the community to develop the scientific case, the necessary tools
- Work with accelerator community to support the R&D effort