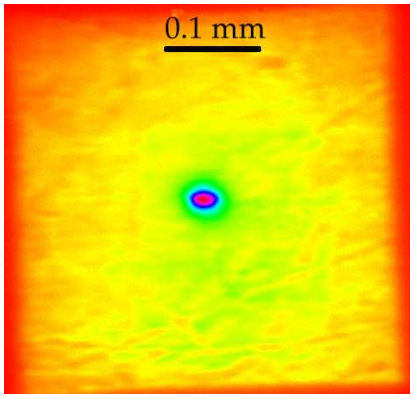
Larger aperture refractive lens for x-rays



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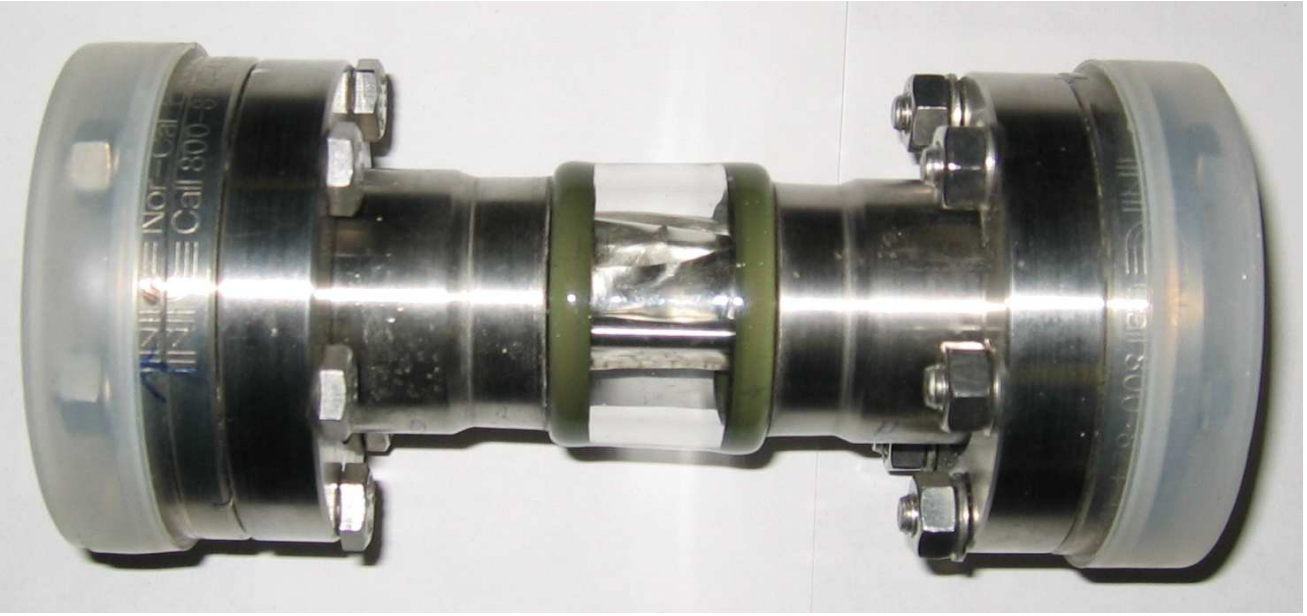
Summary: X-ray refraction & optics

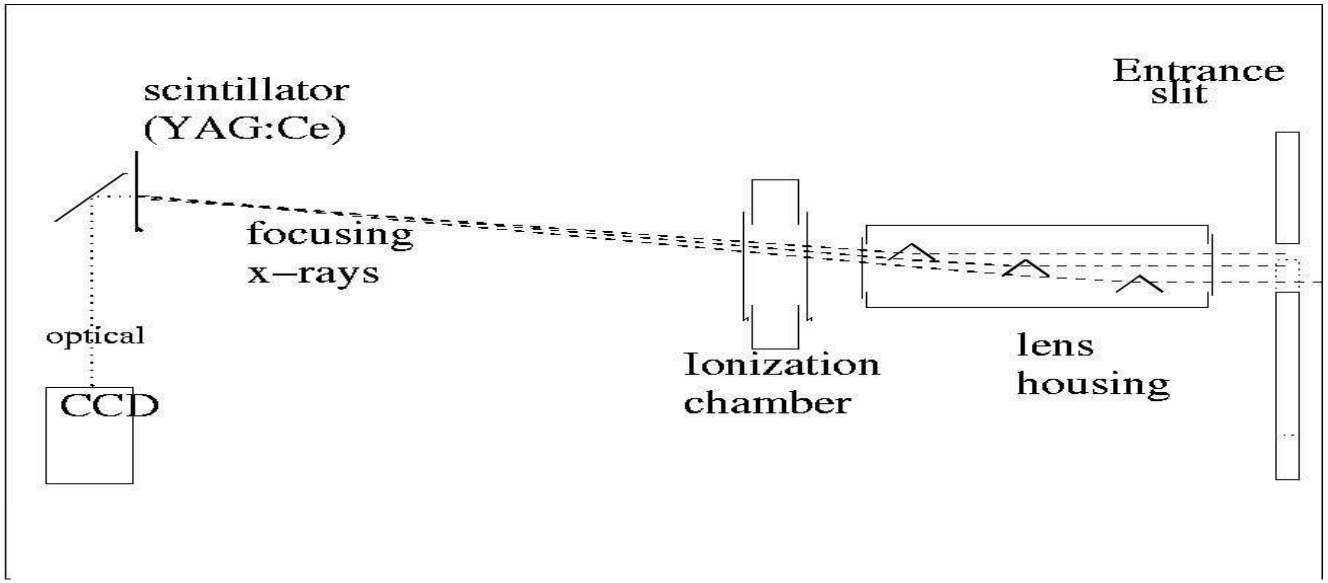
- index of refraction $n = 1 - \delta + i\beta$
  - classical: for photon energy $\hbar\nu$, $\delta = (\omega_p/\omega)^2$
  - $i\beta$ = attenuation (mostly photoelectric)
- Figure of Merit δ/β: lithium's is largest
- $\rightarrow$ refractive optics from lithium
  - lens (parabolic, Aachen design)
  - multi-prism (Cederstrom)
  - lithium handling under control
- representative results (at 10 keV, on APS):
  - large (1 mm) aperture, good ($\simeq$ 50 %) transmission
  - focus $\sim$ 2 m, spot size $\simeq 30\mu$m

Packaging for lithium lenses



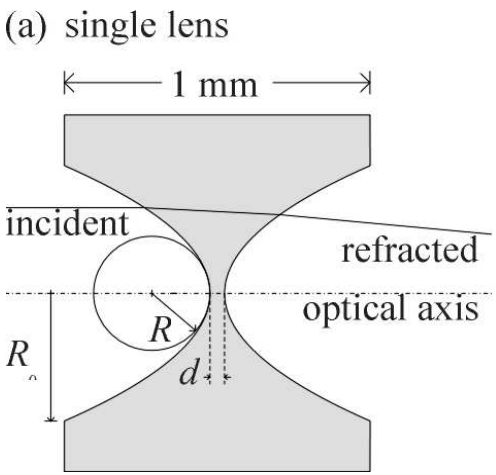
- Hermetic, He-filled, Be windows
- survives for years

Experimental setup



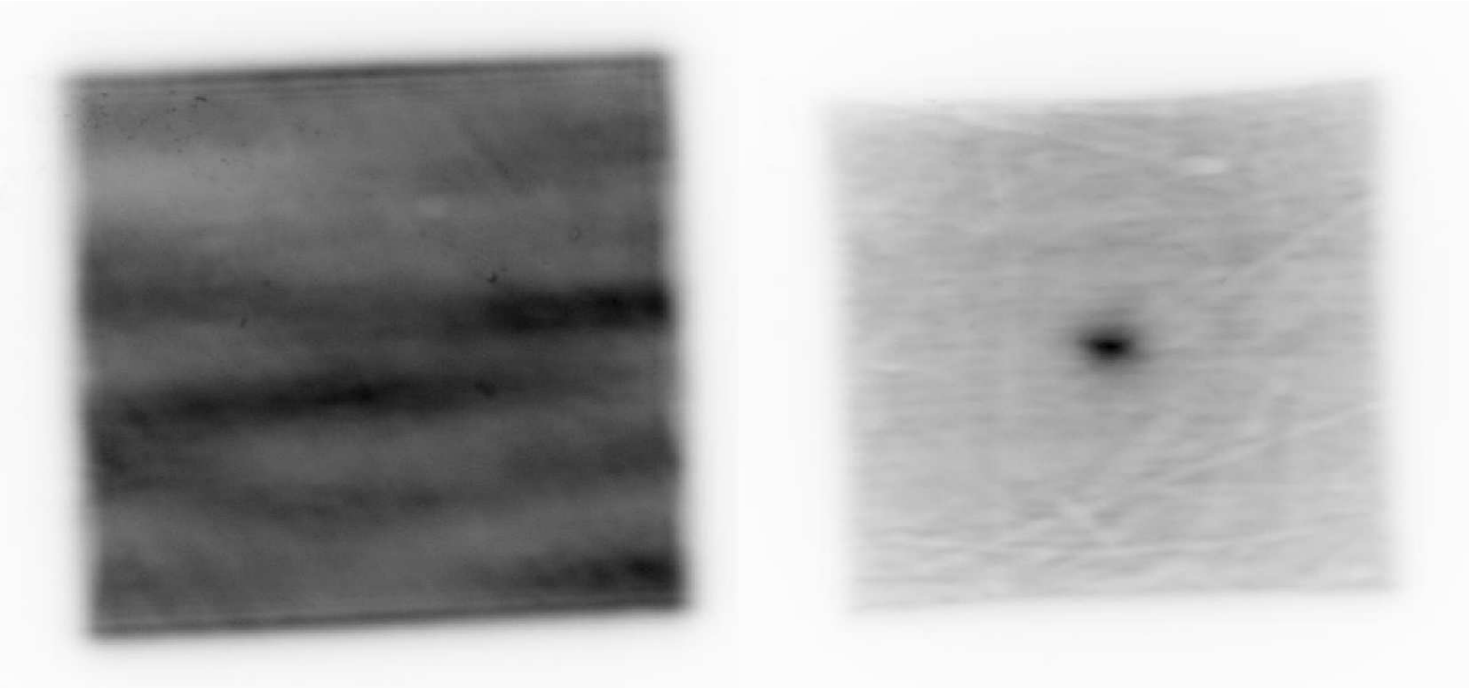
- Easy to align, measure qualitatively (& quantitatively: Dufresne, SRI-2003)

Parabolic lens (Aachen)



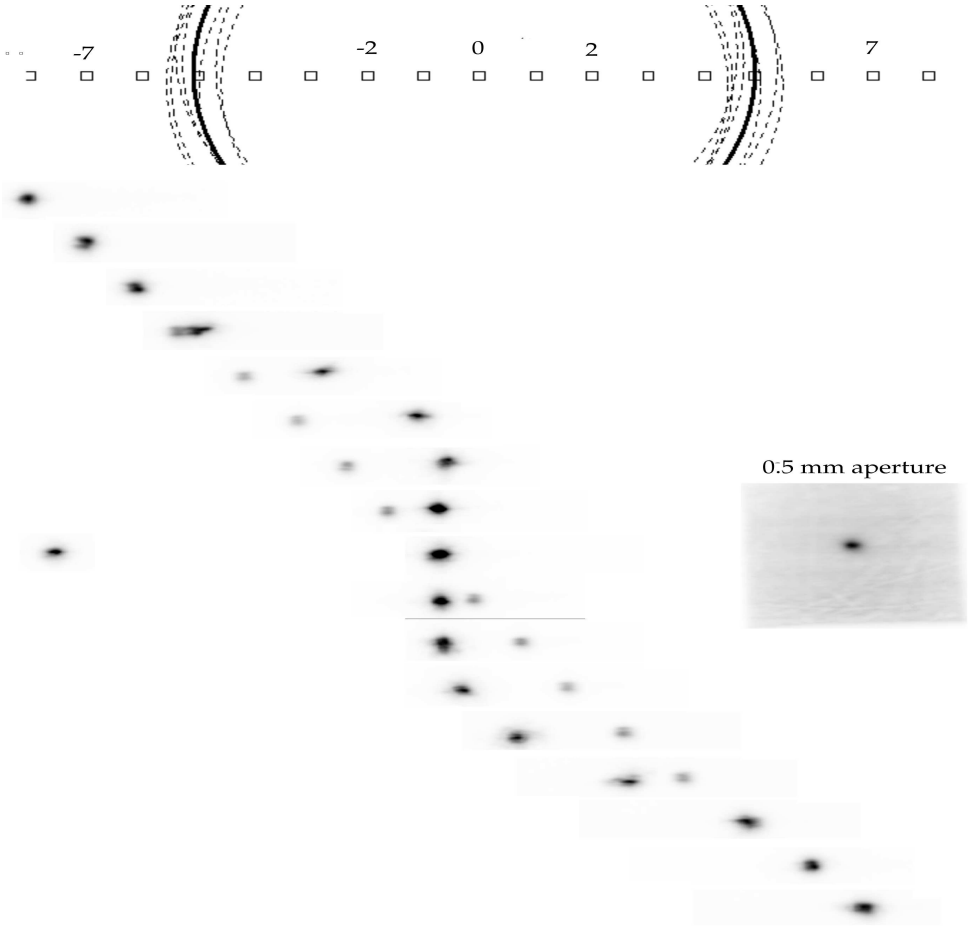
- Standard optics:
  - focal length: $f = R/\delta$ (for plano-concave lens)
  - $\delta \simeq 10^{-5}$, $f \simeq 100$ m (Suehiro, 1991)
  - $f = R/2N\delta$ for N: Compound Refractive Lens
  - $f \simeq 1$ m (Snigirev,1996)
- parabolic lens advantages:
  - spherical aberration absent
  - aperture decoupled from radius & focal length

Lithium parabolic lens performance



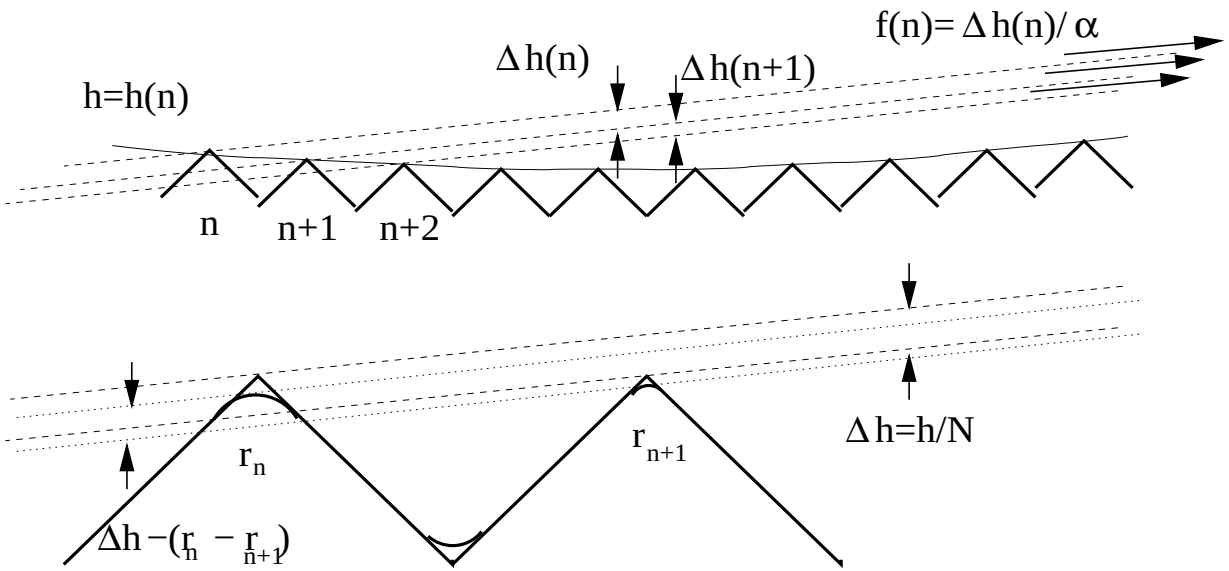
- Gain $\simeq$ 50, transmission $\simeq$ 0.5.
  - gain, size of focus limited by fabrication issues, &
  - fundamental problem with (Li) material (?)

Spatially resolving lens quality



- 20 μm square beam: improvements possible

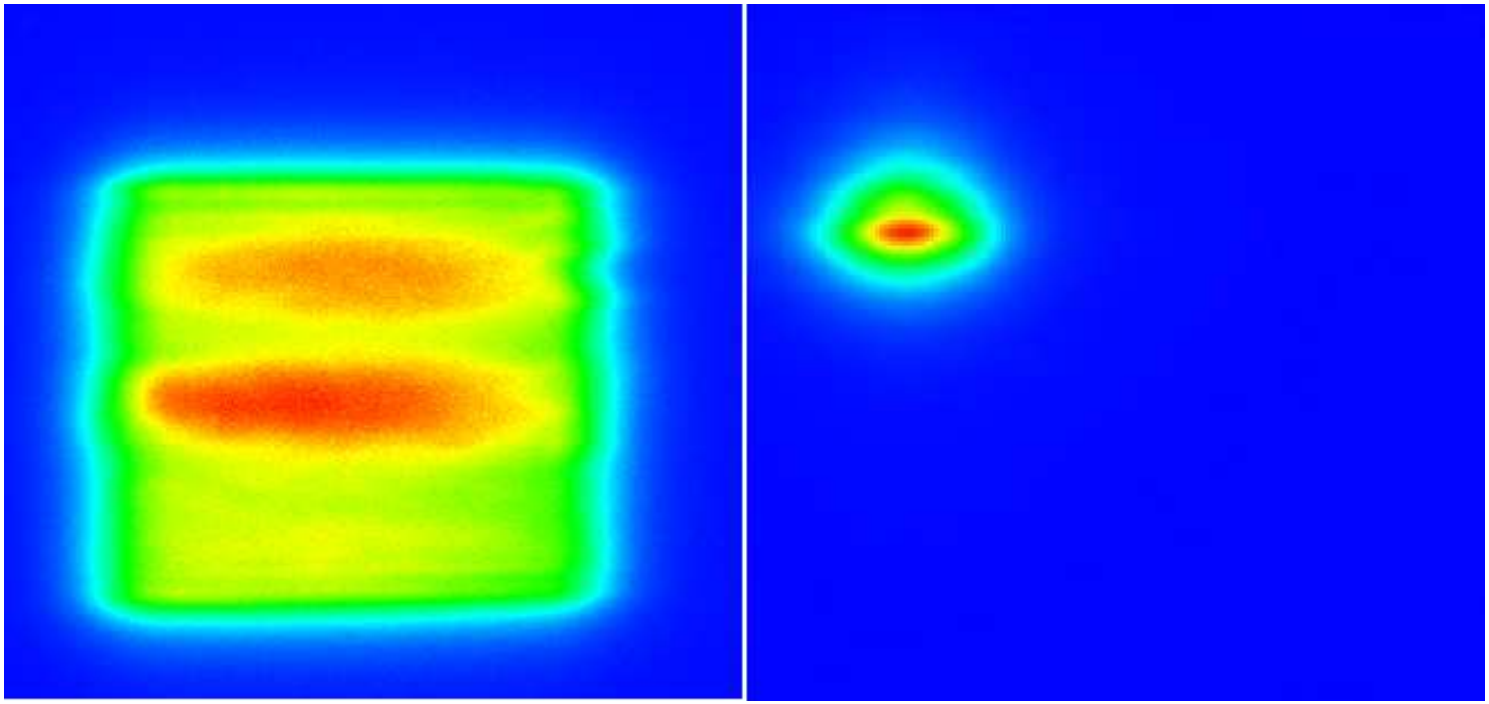
Cederstrom's multi-prism (Nature, 2000)



height = $z/L(1+z/L_c)$

- Specific to x-ray refraction: small deflection approximates parabola
  - features: adjusable focus, away from optical axis
  - need 4 multi-prisms give full 2-D focusing

Lithium multi-prism 2-D focusing



- Gain $\simeq 20$, transmission $\simeq 0.5$.
  - gain, size of focus limited by fabrication issues, &
  - fundamental problem with (Li) material (?)

How useful is lithium refractive optics?

- large aperture (mm), (relatively) large focus ($\simeq$ 10's of μm)
- good transmission ($\simeq$ 0.5)
- robust, low cost
  - 5-stage manipulator most costly item
  - Li lens itself: $\simeq$ \$ 5,000