Optics Needs for Future Light Sources

a summary of the

SLAC/DESY Workshop on Interactions of Intense Sub-Picosecond X-rays with Matter

(SLAC, January 1997)

John Arthur

SSRL/SLAC

ICFA Workshop on Future Light Sources

Advanced Photon Source

April 6-9 1999

SSRL

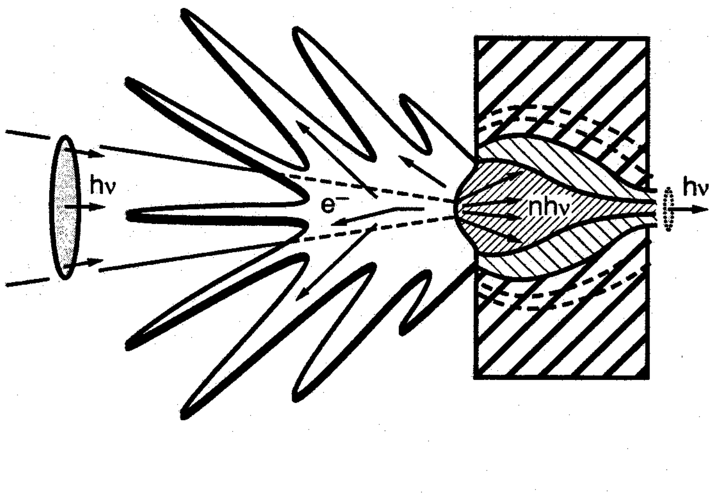
SLAC/DESY International Workshop on Interactions of Intense Sub-picosecond X-Rays with Matter

Stanford Linear Accelerator Center, Stanford, CA
January 23-24, 1997

Organization, Program, and Executive Summary

R. Tatchyn, G. Materlik, A. Freund, J. Arthur

SLAC-WP-12



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STANFORD LINEAR ACCELERATOR CENTER
STANFORD SYNCHROTRON RADIATION LABORATORY
Stanford University • Stanford, California

Objectives of the workshop

- Tutorials on existing theory + experiment
- Discuss optics + instrumentation issues related to high power
- Consider novel optical concepts
- Stimulate R&D programs in theory, numerical simulation, and experiment

Workshop Logistics

2 days at SLAC in January 1997

30 participants, from 5 countries and 13 institutions

Proceedings available from SSRL

Reviews and Tutorials

G. Materlik (DESY) Properties of DESY FELs

R. Tatchyn (SLAC) Properties of SLAC FEL

R. More (LLNL) General review of high-power EM field interactions

K. Rzazewski (Polish Academy, Warsaw) Theory of EM field interaction with atoms

B. Newnam (LANL) Laser damage studies

Proposed XFEL experiments

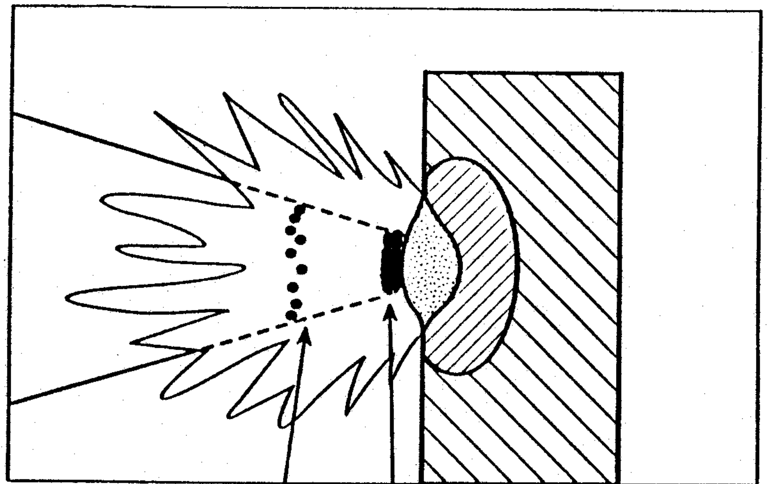
J. Krzywinski (Polish Academy/DESY), S. Doniach (Stanford), J. Feldhaus (DESY), J.-F. Eloy (CEA/CESTA)

Optics + optics tests

A. Freund (ESRF), M. Howells (LBNL), E. Foerster (Jena), H. Schulte-Schrepping (DESY)

From presentation by R. More

Laser interaction physics



- Plasma instabilities (Raman, Brillouin) where $\omega_L = 2\omega_p$
- Laser refraction by plasma

- Inverse bremsstrahlung
- Resonance absorption

Absorption and reflection where $\omega_L = \omega_p$

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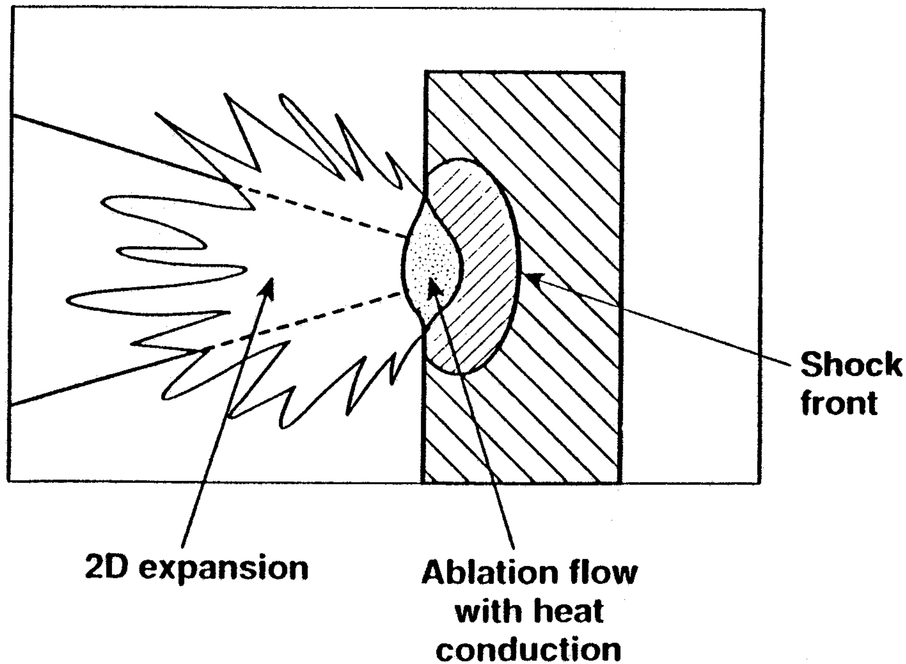
Hydrodynamics:



- Equation of state p(ρ T), E(ρ, T)
- Ionization state Q(ρ, T)

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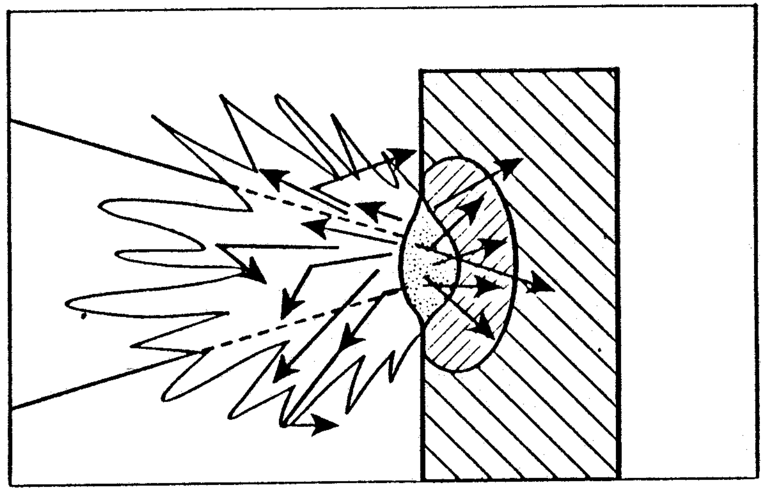
Superthermal electrons (E = 10-100 keV)



- Production mechanism is not completely understood
- Electrons transport energy over large distances

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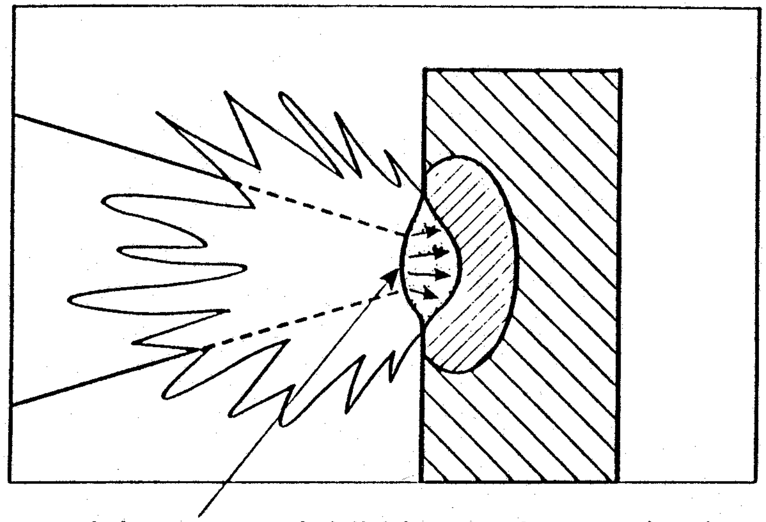
Thermal electron heat conduction

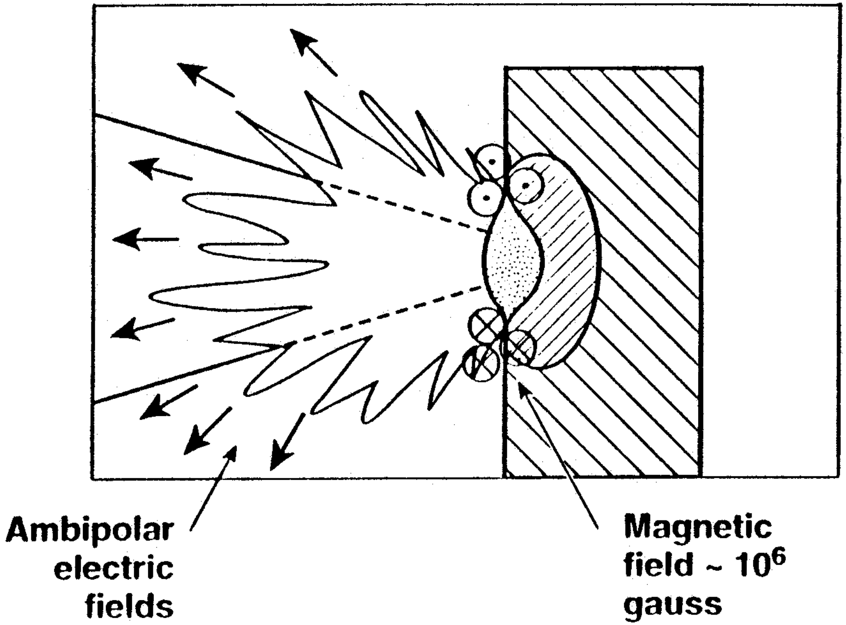


Substantial transport inhibition for long-pulse lasers

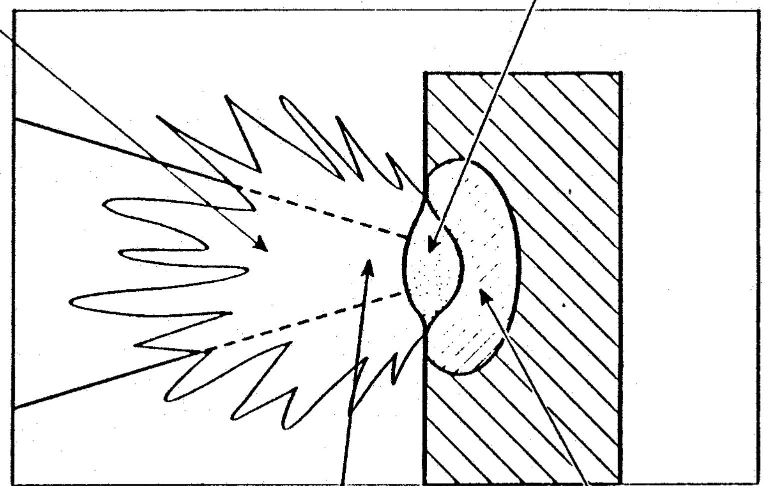
Conjectured explanations include

- Turbulence
- Large magnetic fields
- Non-Maxwellian electron distributions

Large electric and magnetic fields



Atomic ionization



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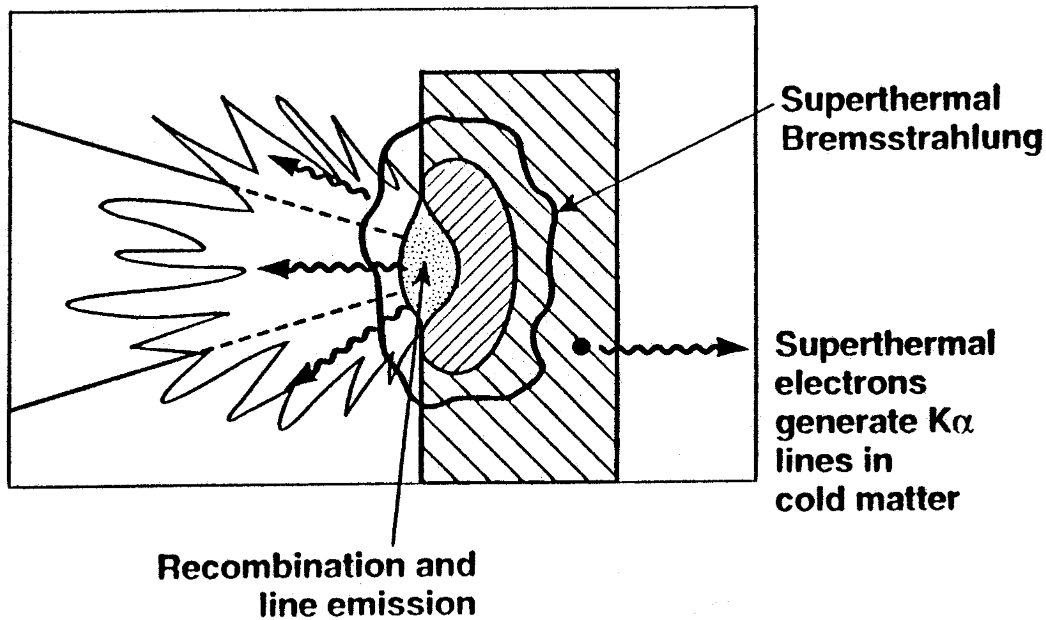
Laser plasmas emit X-rays in several ranges of energy



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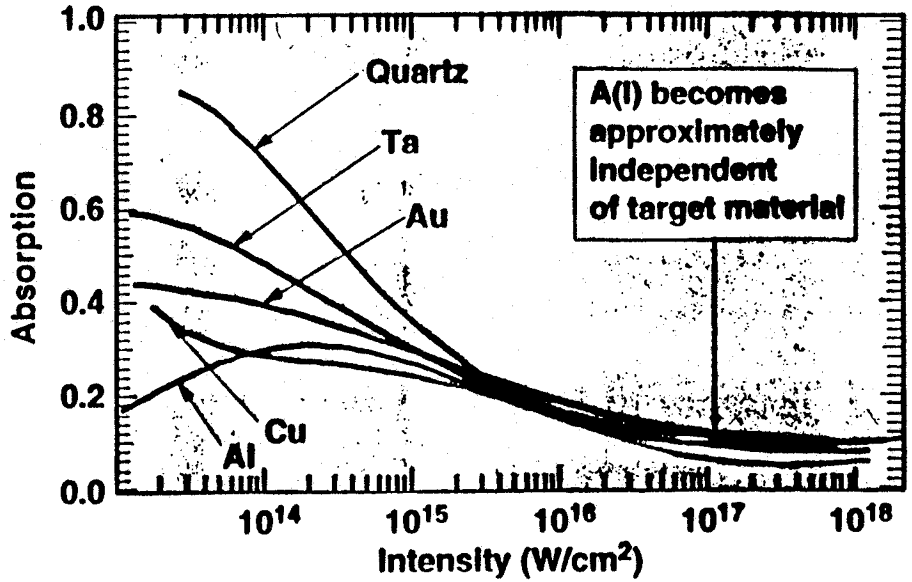
Absorption depends on the target material

At high intensity, observe *Universal Plasma Mirror* reflection



Low Intensities:

- Conduction electron inverse bremsstrahlung
- Intra–atomic line absorption (interband transitions)

High Intensities:

- Free electron/ion inverse bremsstrahlung
- Novel mechanisms above about 10^{18} Watts/cm^2

Workshop Conclusions

1) Time scale considerations

XFEL pulse length is longer than some interaction time scales, shorter than others. An understanding of the interaction must be aware of these time scales.

Electron response: attosec - femtosec

Atom response: femtosec - picosec

Lattice response: picosec - nanosec

Energy conversion and transport processes have different time scales: electron emission, radiation, lattice vibration, diffusion

2) Wavelength considerations

Electron response to EM field depends on frequency. Interaction cross sections are different, so are amplitude and velocity of induced electron motion

This implies that femtosec laser studies do not accurately simulate XFEL

3) Nonlinear response

For field strengths at or slightly above those of unfocused XFEL, nonlinear effects are likely to become important

multi-photon absorption

tunneling ionization

multi-electron ionization

Detailed calculations in the x-ray range have not yet been done

Primary conclusion of workshop:

Much is not known about the interaction of an XFEL pulse with matter

Theoretical work and numerical simulation could help greatly in this area

Simple, conservative optics techniques for mitigating the damage problem

1) Spread the power in space or time (long beamline, glancing incidence)

2) Reduce the power using an absorber (gas or liquid attenuation cell)

3) Use expendable optics

4) Use simple optics

Demands on XFEL optics and detectors will be unprecedented and severe

- Must handle high peak power
- Preservation of spatial coherence
- Path length jitter must be measured in microns
- Detector must have huge dymamic range

Second conclusion of workshop:

XFEL optics will be different from 3rd-generation synchrotron optics

Development efforts should start immediately on XFEL optics and detectors

Caveat: Existing sources will not make it easy to test XFLE optics concepts

All existing x-ray and laser sources differ by several orders of magnitude from XFEL characteristics

But

TESLA facility will come close, and LCLS would provide a fantastic test lab