Frontiers of Imaging at LLNL
Applications and Technology Overview

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New developments in optics, detectors, and signal processing technologies are enabling new approaches to optical imaging

New imaging technologies can lead to revolutionary new national security capabilities:

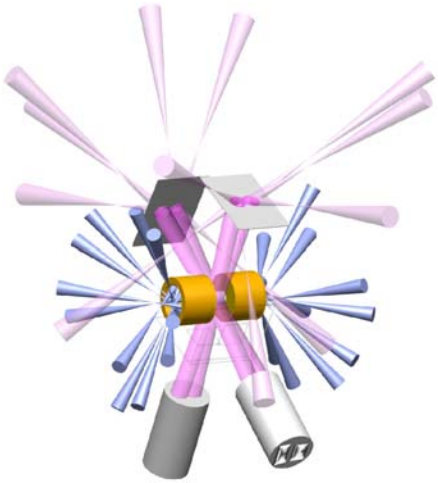
- 3D movies of high energy laser fusions plasmas on 100 fsec time scales
- Detecting and classifying WMD activities anywhere on earth
- Detecting and characterizing clandestine nuclear or radiological devices

The same technologies lead to new scientific applications:

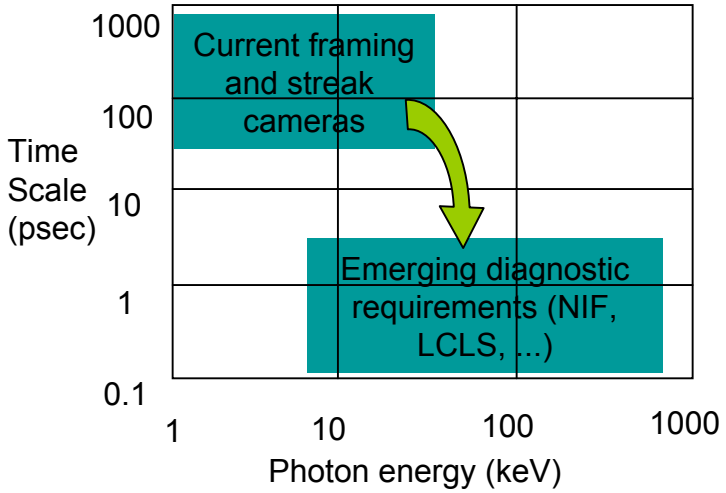
- Direct imaging of single biomolecules at atomic resolution
- Directly imaging an extrasolar planet and measuring its spectrum

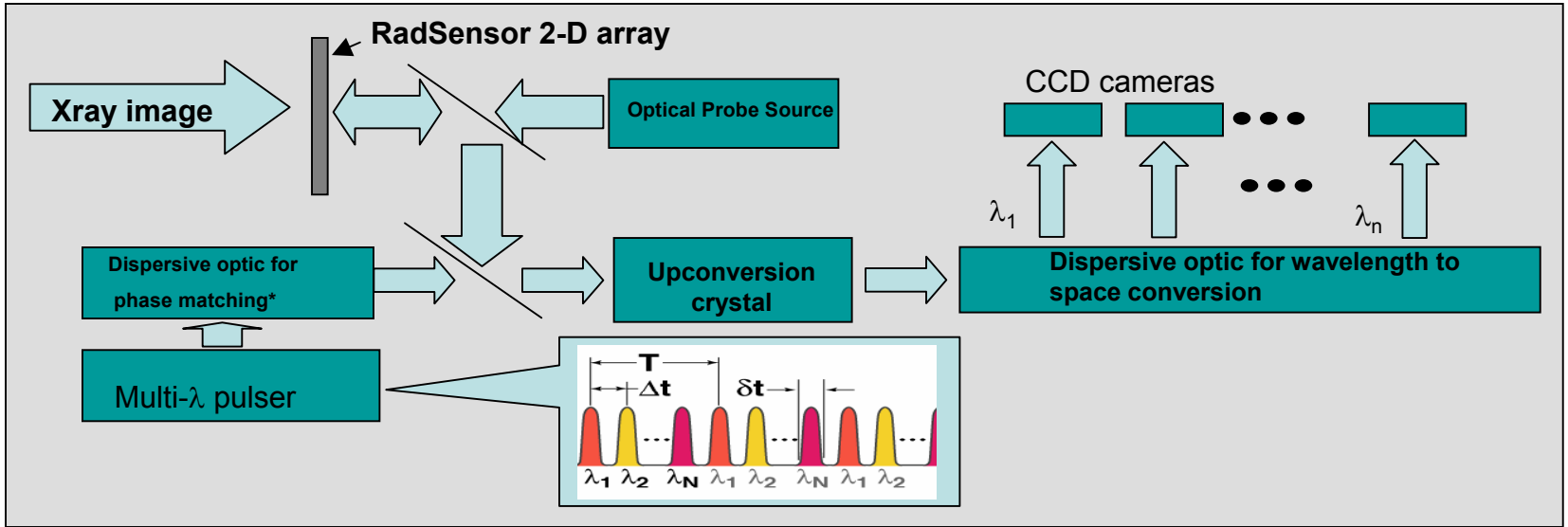
Pushing temporal limits – x-ray framing cameras at sub-picosecond frame times

3D imaging enabled by new x-ray optics and detector technologies

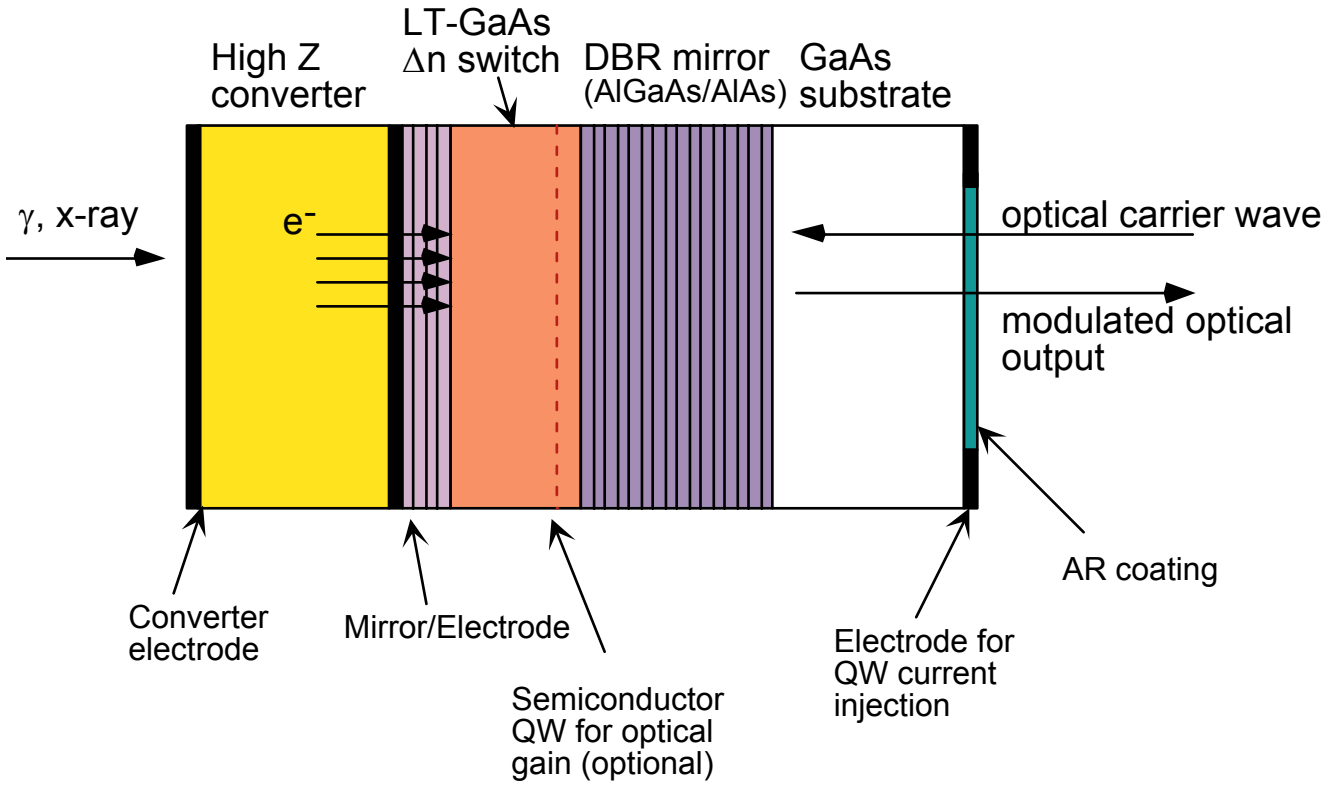


Future diagnostics require high energies at short time scales



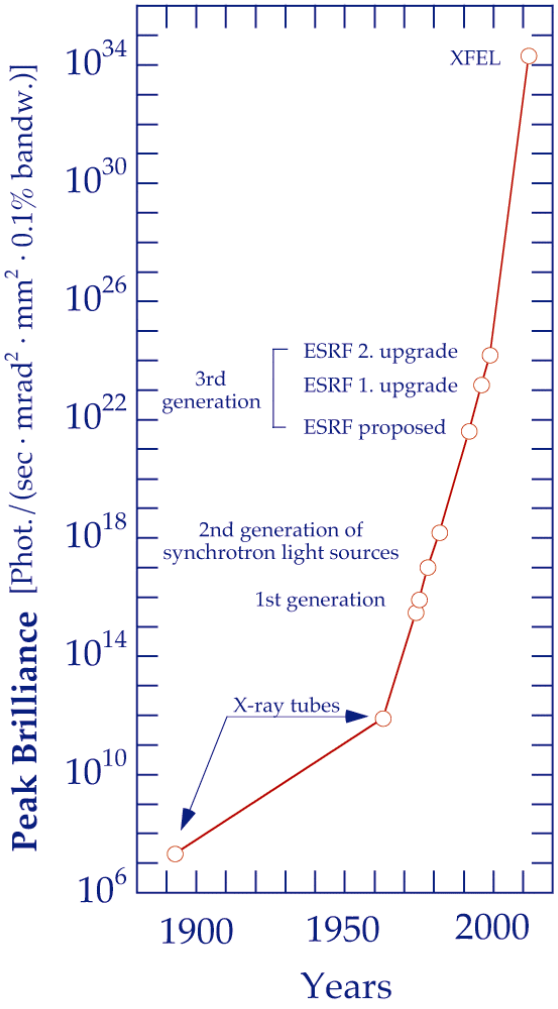


Imaging Detector Structure

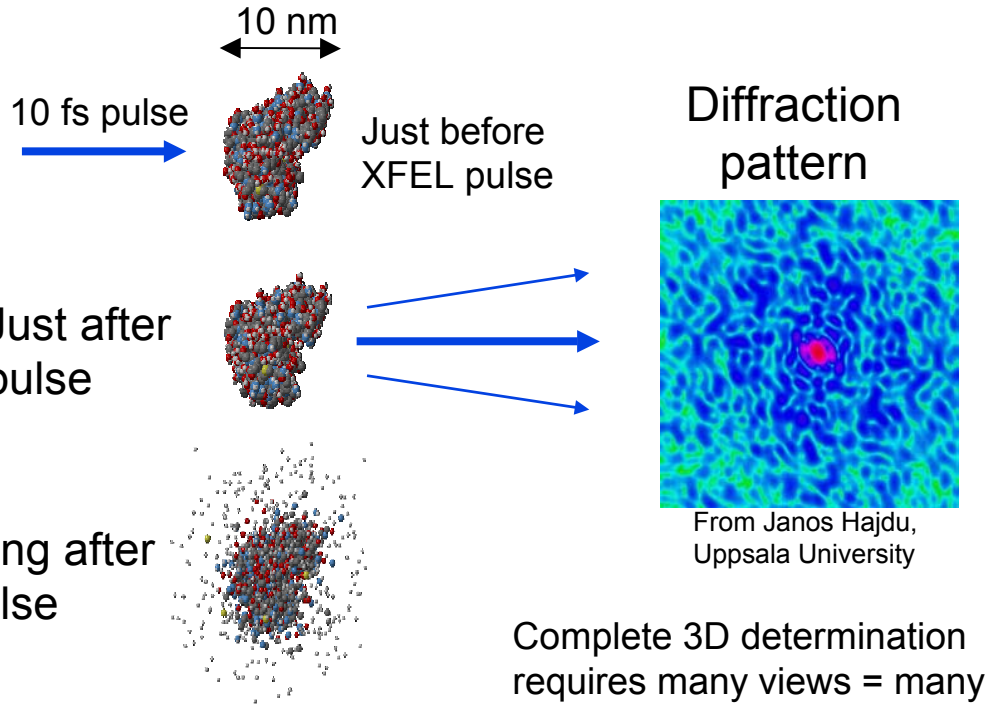


VCSEL-like structure represents one pixel and can be epitaxially grown on a wafer-scale, enabling megapixel xray movies

Atomic-resolution imaging of virtually any biological macromolecule will become possible



Diffraction from a single molecule:



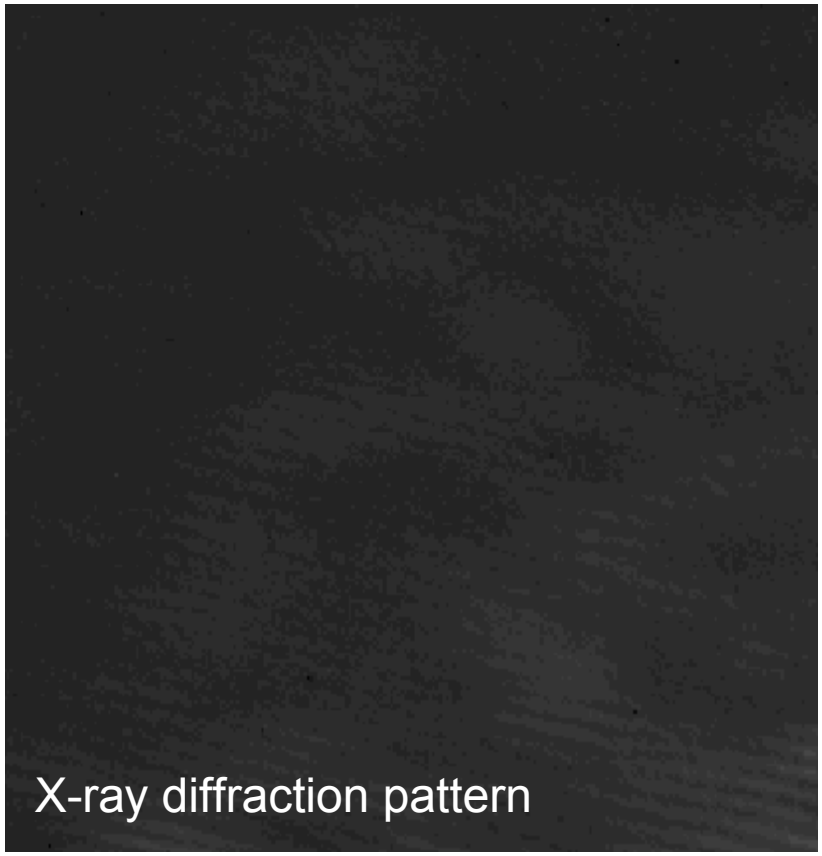
From Janos Hajdu, Uppsala University

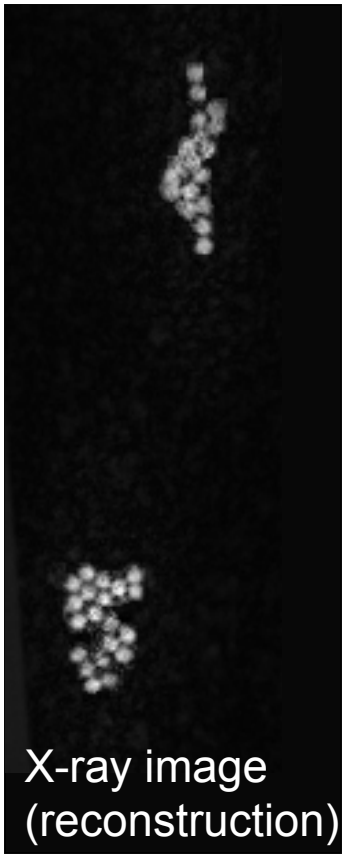
Complete 3D determination requires many views = many identical molecules

Two critical issues need to be solved:

- details of short-pulse photon-matter interactions
- image reconstruction

The image was reconstructed, with no additional image used to guide the reconstruction





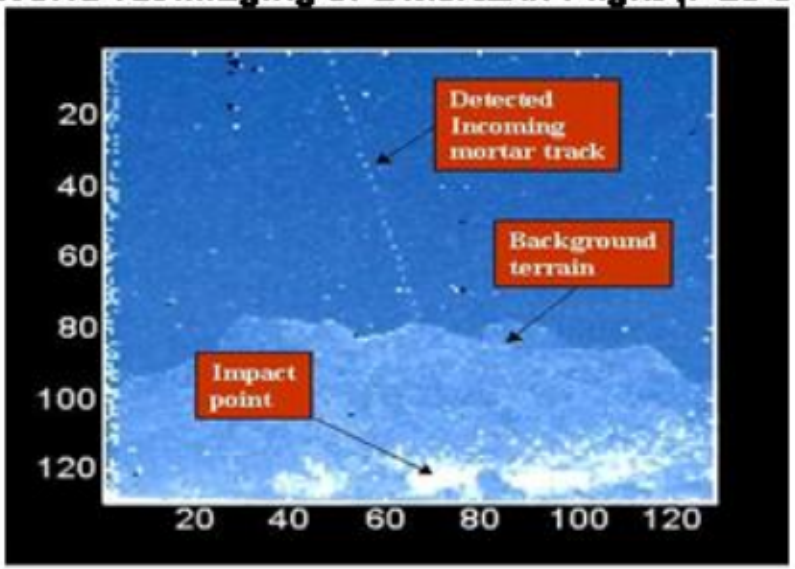
Sample: 50 nm gold spheres
Diffraction recorded at ALS undulator beamline, λ = 2 nm
Resolution of reconstructed image: 20 nm
Reconstruction performed with variation of Gerchberg-Saxton algorithm,
with dynamic support constraint

Stefano Marchesini and Henry Chapman, LLNL

We Have Demonstrated LifeGuard as A Thermal Imaging System for Tracking Bullets and Artillery Shells

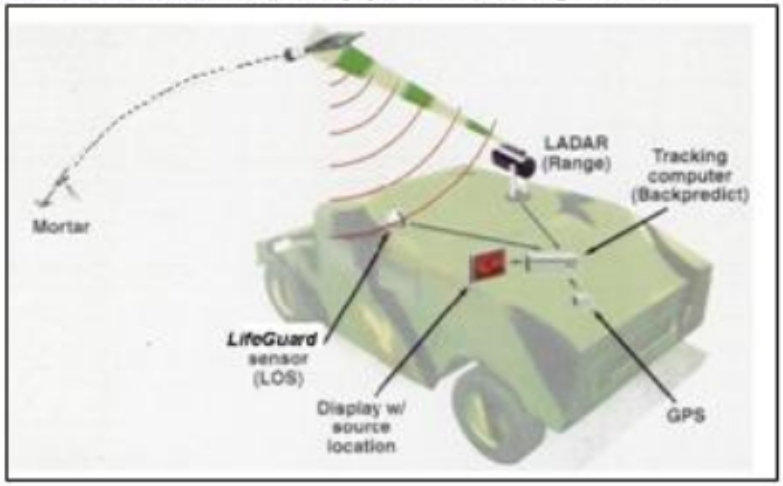
World 1st Imaging of Bullet in Flight (6-15-93)

World 1st Imaging of a Mortarin Flight (7-28-94)



A Counter SniperScope System

A Counter Fire Suppression System



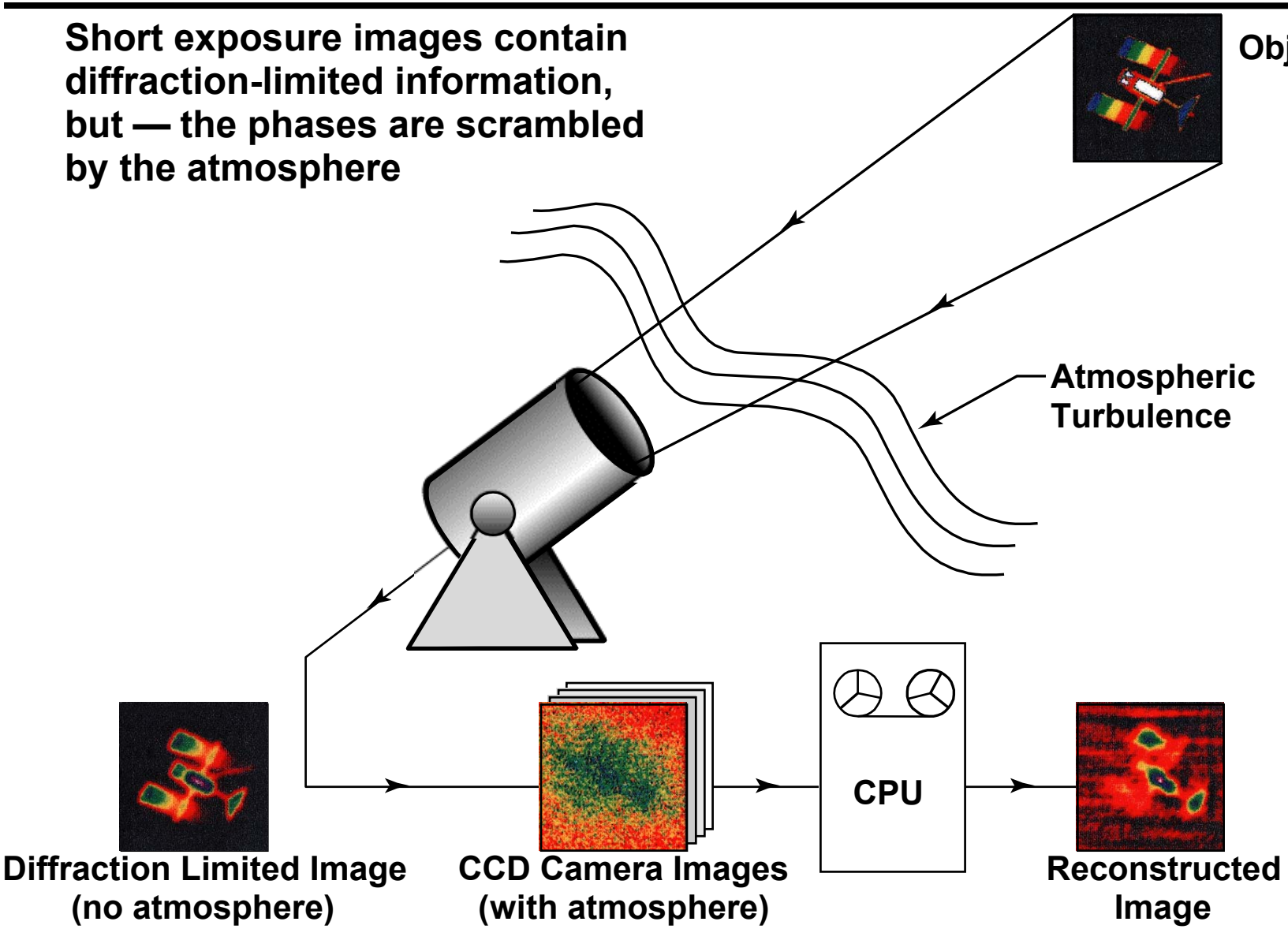
Lifeguard I (1993) Demo System Sensor Specifications

Parameter	1993 Demo*
material	InSb
waveband, μm	3-5
quantum eff	40%
number of pixels	128 x 128
frame rate, Hz	217
readout	raster
bits	12
noise bits	1-2
BLIP limit	< 20%
pixel size, μm	50
FOV	16°
pixel IFOV, mrad	2
cooling	LN2
ruggedization	NA

* Note that current experiment senso
electronic noise >> intrinsic back

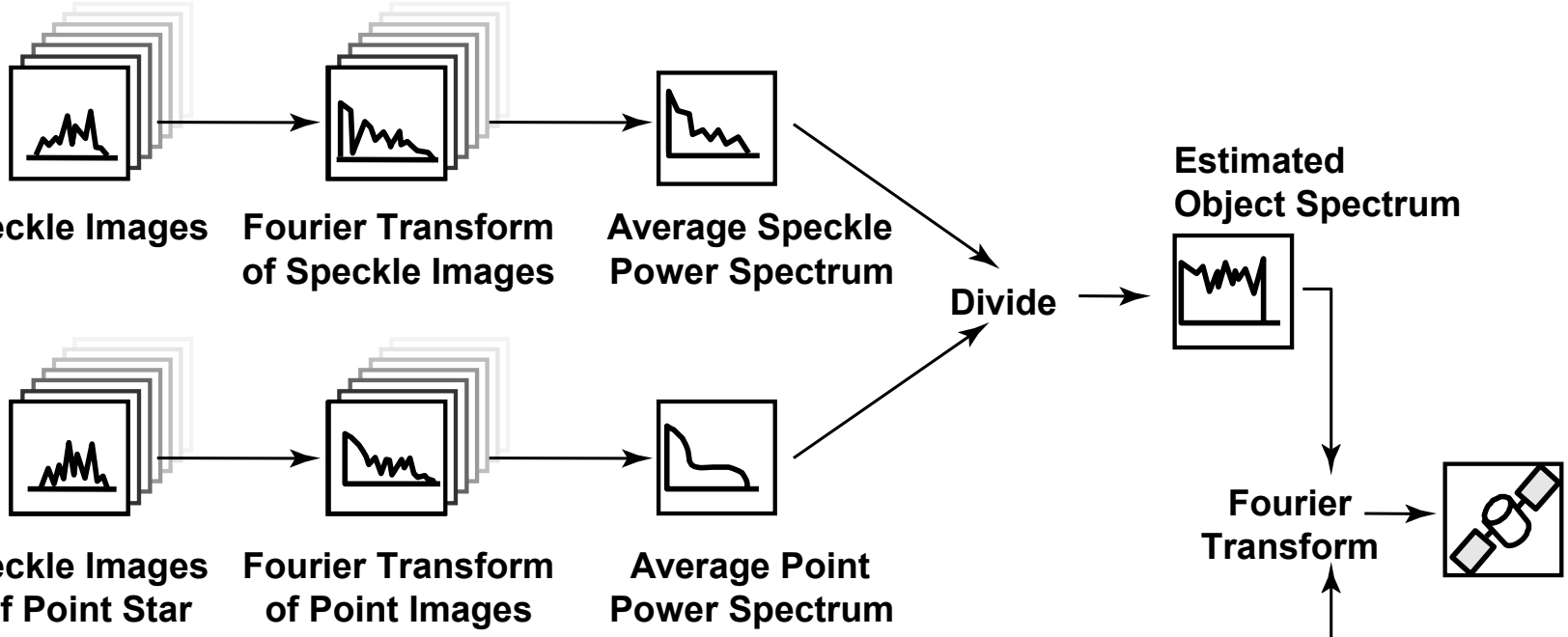
Speckle Imaging for High Resolution Surveillance

Short exposure images contain diffraction-limited information, but — the phases are scrambled by the atmosphere

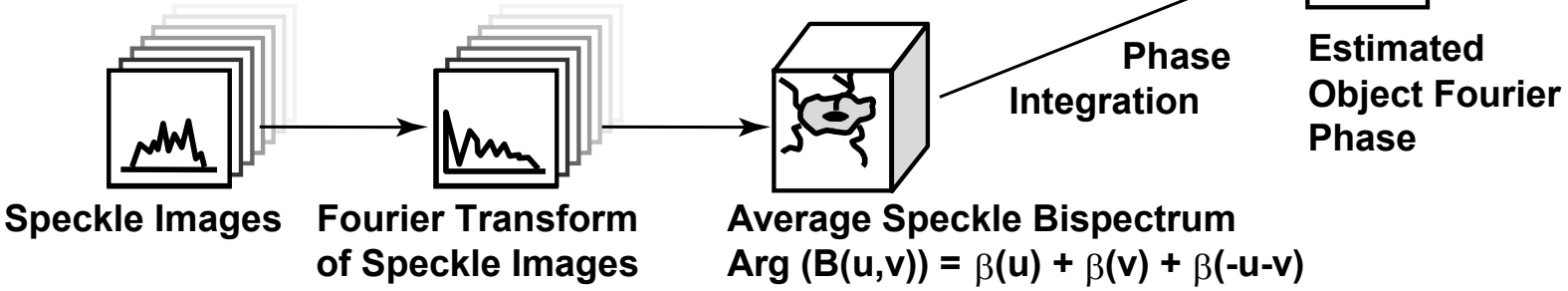


The Fourier magnitude and phase can be estimated from speckle image sequences

- **Fourier Magnitude Estimate Using Speckle Interferometery**



- **Fourier Phase Estimate Using Speckle Masking**



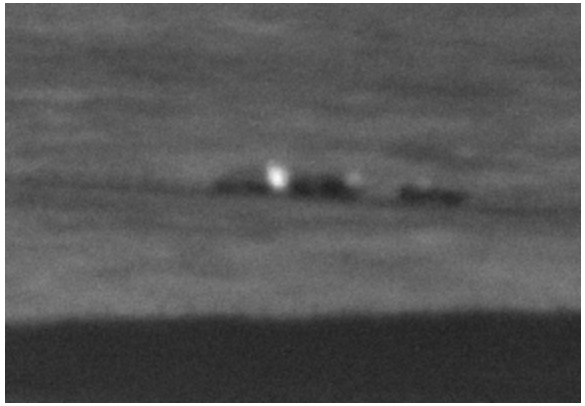
People and resolution targets from 3.3 km range

Shift and Add

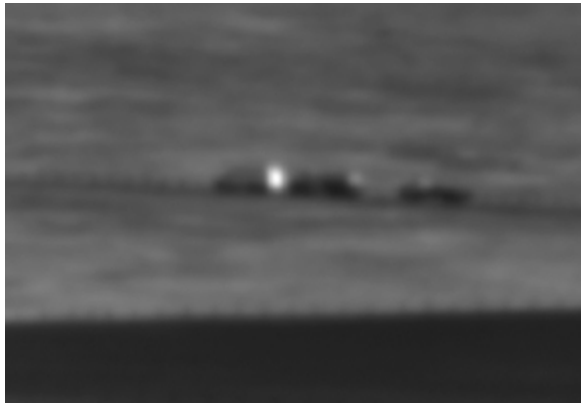
Speckle tile processed

100 frames
15 ms exposures
256x256 sized tiles
60% Hanning apodization
Set r_0 = 2.0 cm

Trucks at 22 km range



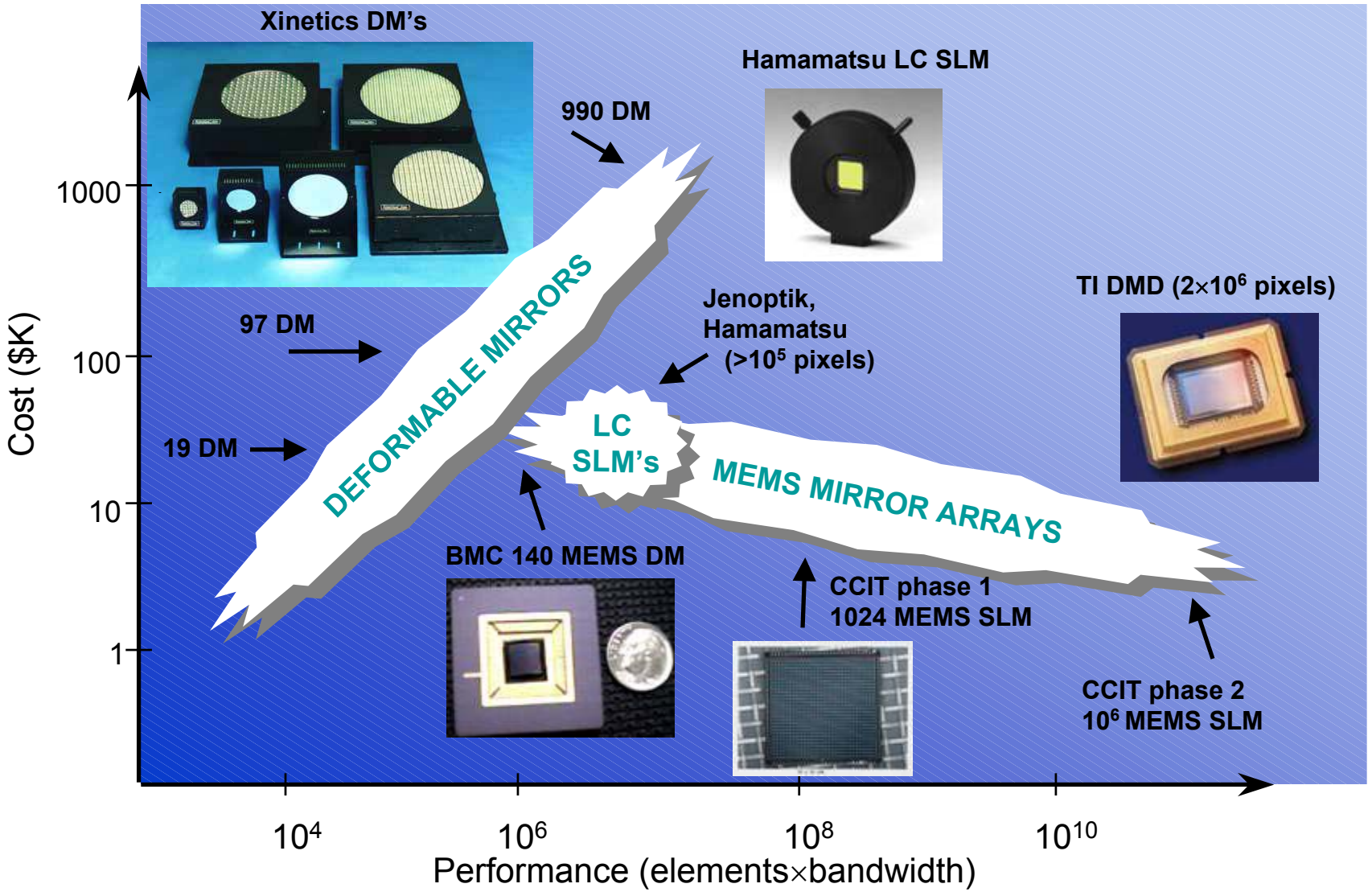
Sample frame



Shift and add 100 frames

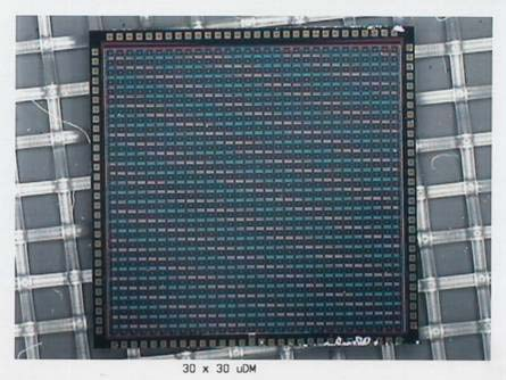
20 cm aperture
dt = 0.9 ms
Flat-field gain correction
Speckle-tile processed 256x256 tiles,
DLmax = 312, proc. to DL= 40
R0 = 1.0 cm (D/r0 = 20)

New wavefront control devices provide dramatically increased capabilities at lower cost



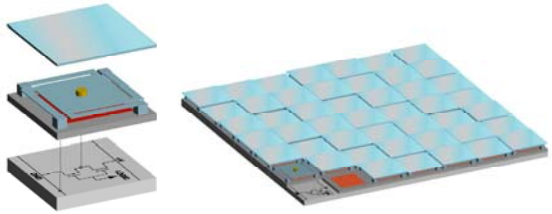
New spatial light modulators being developed by CCIT and CfAO enable precision optical control

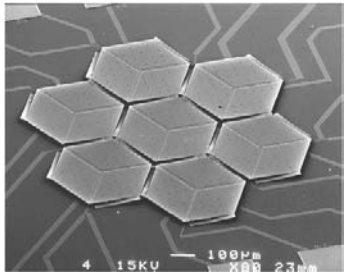
- **Pushing SLM technology to**
  - Large formats (1024x1024 phase control points)
  - Fast temporal response (10 μs)
  - High optical quality (20 nm)
- **High resolution phase control enables new applications**
  - Arbitrary space-time optical codes
  - Programmable diffractive optic
  - High-resolution aberration correction
  - Direct intensity control – designer psf's



1000 actuator MEMS DM developed at Boston University

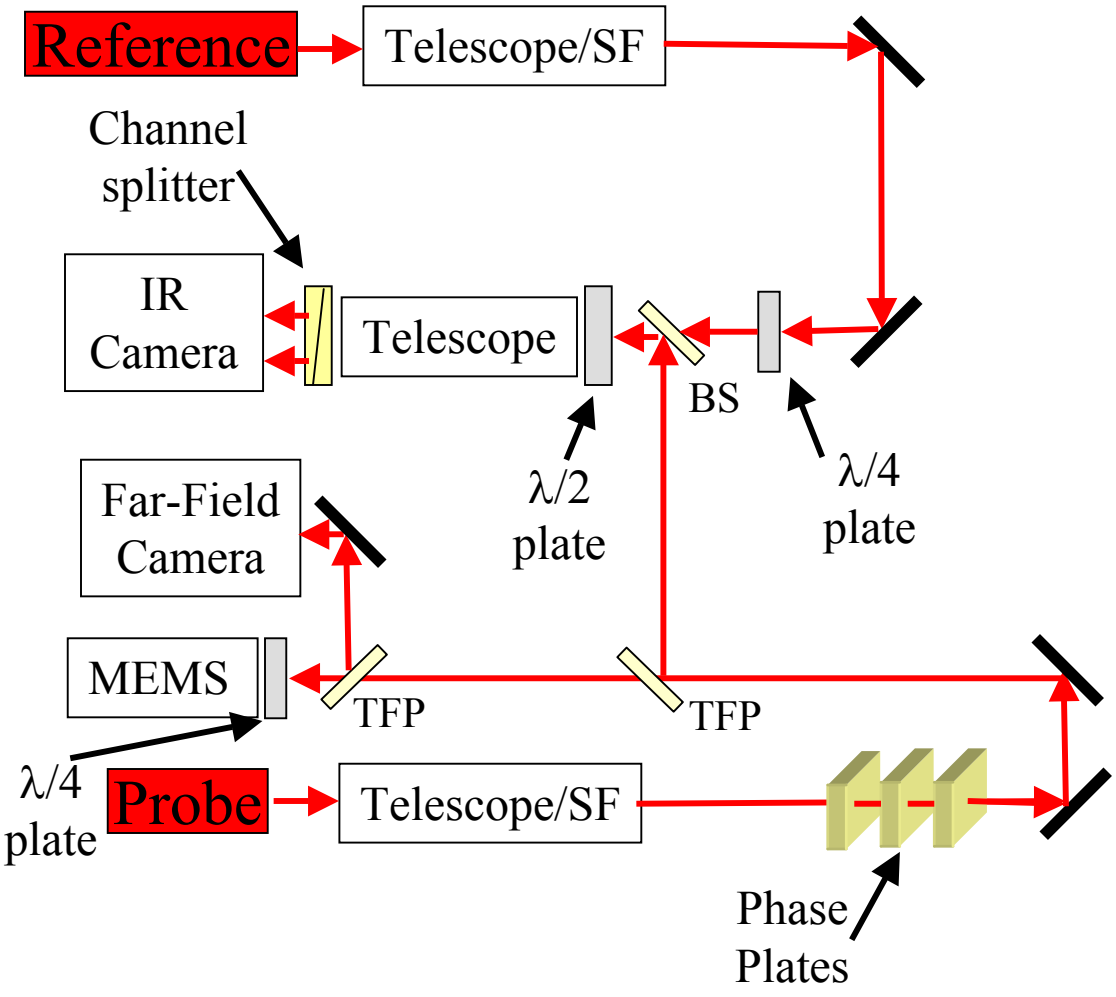
Design concept for MEMS SLM integrated with electronics





High-stroke MEMS DM developed at UC Berkeley

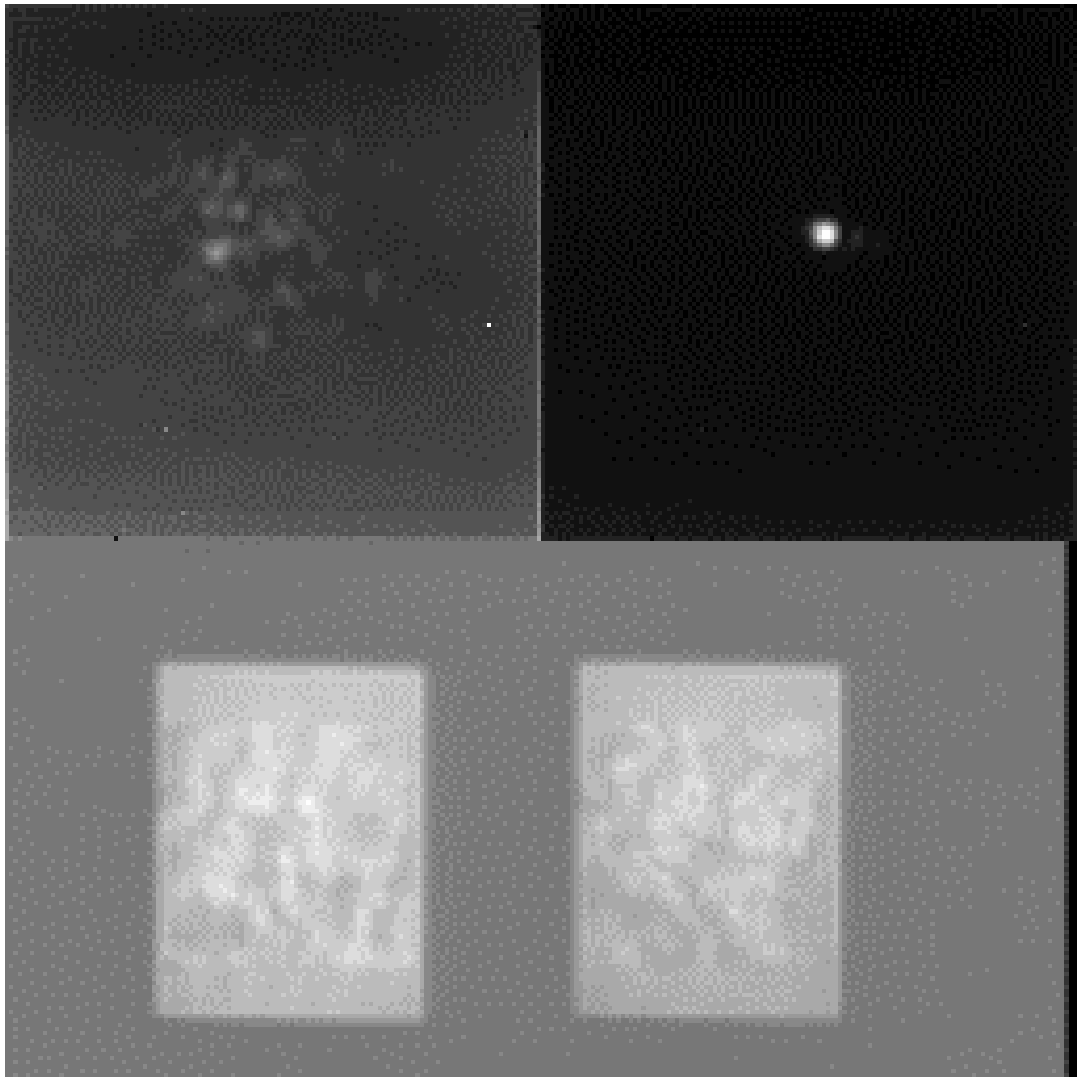
IR Laboratory Breadboard Optical Layout - Open Loop (E. Stappaerts, K. Baker)



- Laser is an Erbium doped fiber laser at 1530 nm.(1 ns pulse, 1khz rep. rate, 2 separately triggered arms with 8 μJ and 130 nJ)
- Polarization out of the probe laser is linear (45 degrees)
- Polarization out of reference is made linear and vertical
- Reference is circularly polarized by QWP
- HWP rotates vertical polarization by 45°; quadrature receiver separates & interferes vertical and horizontal components of reference and probe beam
- QWP in front of MEMS rotates the polarization 90 degrees by the second pass.

Far-field Pattern with Rotating Phase Plates

Uncorrected Far-field (Movie)

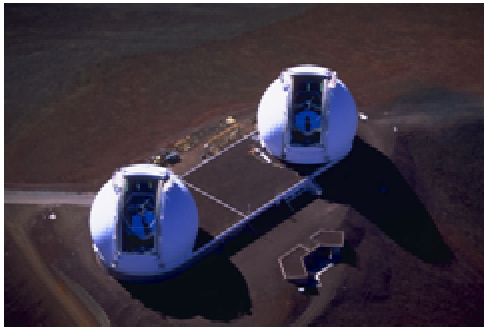


Corrected Far-field (Movie)

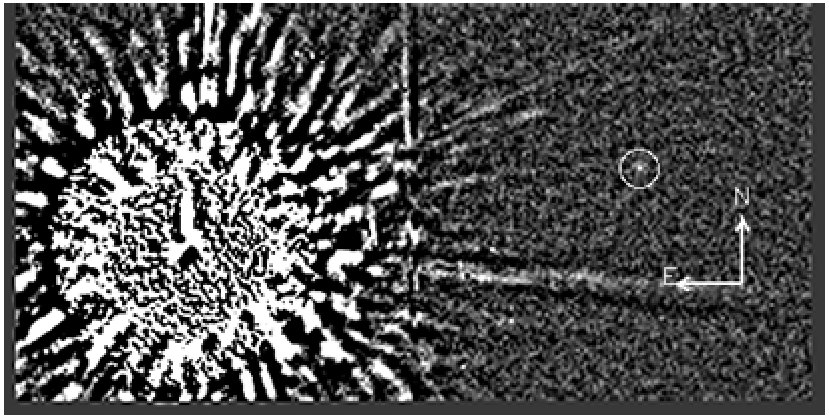
Interferogram Channels (Movie)

K. Baker, LLNL

Center for Adaptive Optics Astronomical Themes

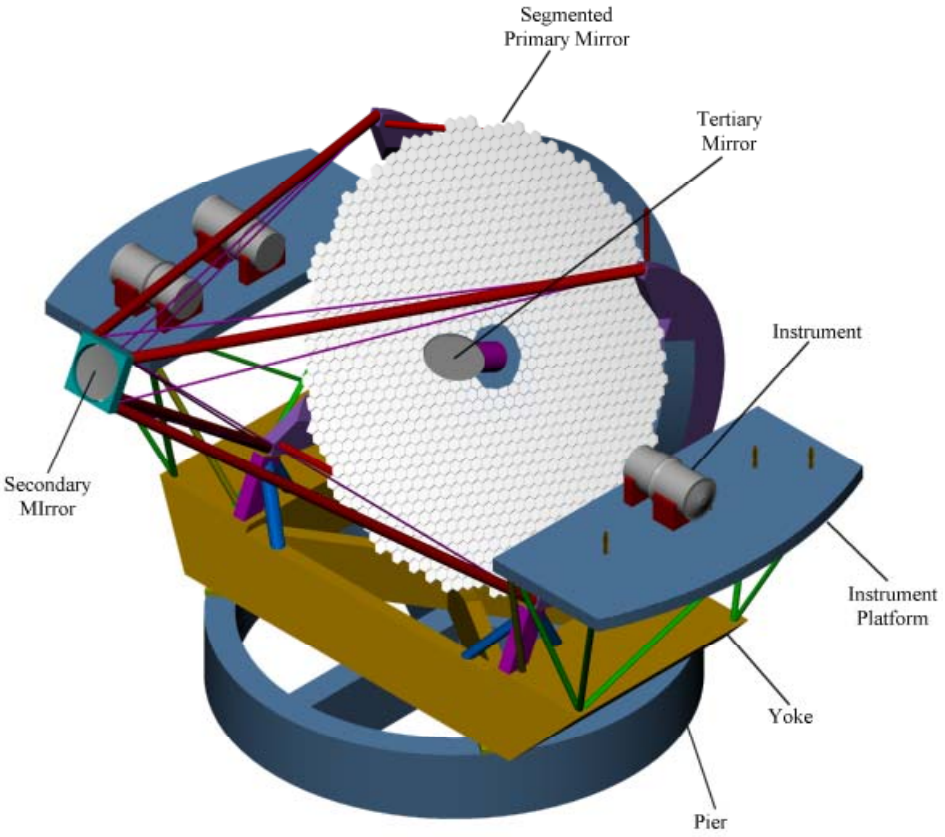


Extreme adaptive optics that enable <u>ultra-high-contrast</u> **astronomical observations**



Adaptive optics for

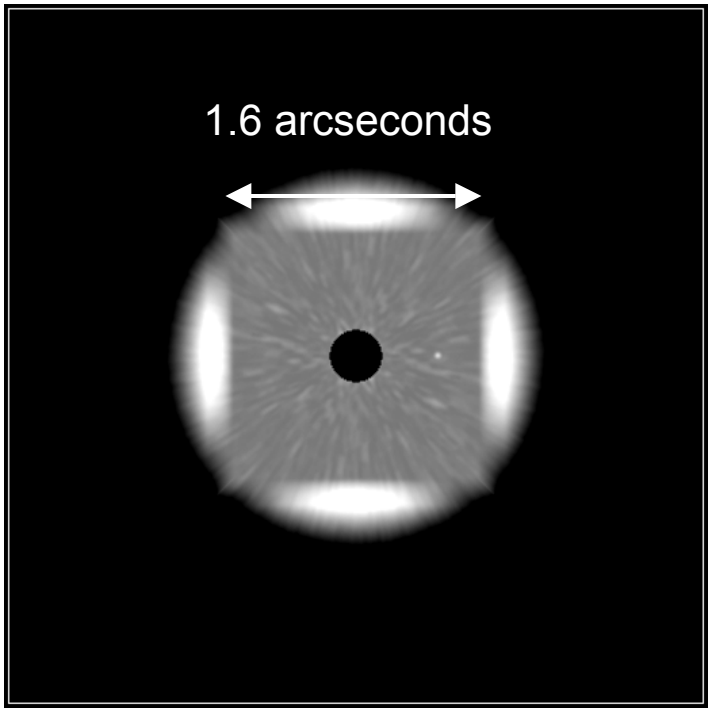
<u>extremely large telescopes</u>



Development of adaptive optics systems for these applications requires new high-performance, affordable wavefront corrector technology.

eXtreme Adaptive Optics Planet Imager: XAOPI (B. Macintosh, LLNL)

- A ~3000 actuator AO system for an 8-10m telescope
- Science goals:
  - direct detection of extrasolar planets
  - characterization of circumstellar dust
- Status: 2002-3 Conceptual design study
  - System could be deployed in 2007
- LLNL, UC Berkeley, UCSC, UCLA, Caltech, JPL team
- System will be funded by NSF/CfAO and another external agency
- System is intended to be facility-class
  - A wide variety of high-contrast science programs are available
  - System will operate on targets brighter than m_R~7-10



Simulated 15 minute XAOPI H-band image showing a 8 Jupiter-mass planet near a solar-type star