From the Shared Internet to Personal Lightwaves: How the OptIPuter is Transforming Scientific Research

Invited Talk
Cyberinfrastructure Colloquium
Clemson University
April 3, 2008

Dr. Larry Smarr
Director, California Institute for Telecommunications and Information Technology
Harry E. Gruber Professor,
Dept. of Computer Science and Engineering
Jacobs School of Engineering, UCSD

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UCIrvine

Abstract

During the last few years, a radical restructuring of optical networks supporting e-Science projects has occurred around the world. U.S. universities are beginning to acquire access to high bandwidth lightwaves (termed "lambdas") on fiber optics through the National LambdaRail and the Global Lambda Integrated Facility. The NSF-funded OptIPuter project explores how user controlled 1- or 10- Gbps lambdas can provide direct access to global data repositories, scientific instruments, and computational resources from the researcher's Linux clusters in their campus laboratories. These end user clusters are reconfigured as "OptIPortals," providing the end user with local scalable visualization, computing, and storage. Creating this cyberinfrastructure necessitates a new alliance between campus network administrators and high end users. I will describe how this user configurable OptIPuter global platform opens new frontiers in in collaborative work environments, digital cinema, interactive ocean observatories, and marine microbial metagenomics.

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Calit2 Continues to Pursue Its Initial Mission:

Envisioning How the Extension of Innovative Telecommunications and Information Technologies Throughout the Physical World will Transform Critical Applications Important to the California Economy and its Citizens' Quality Of Life.

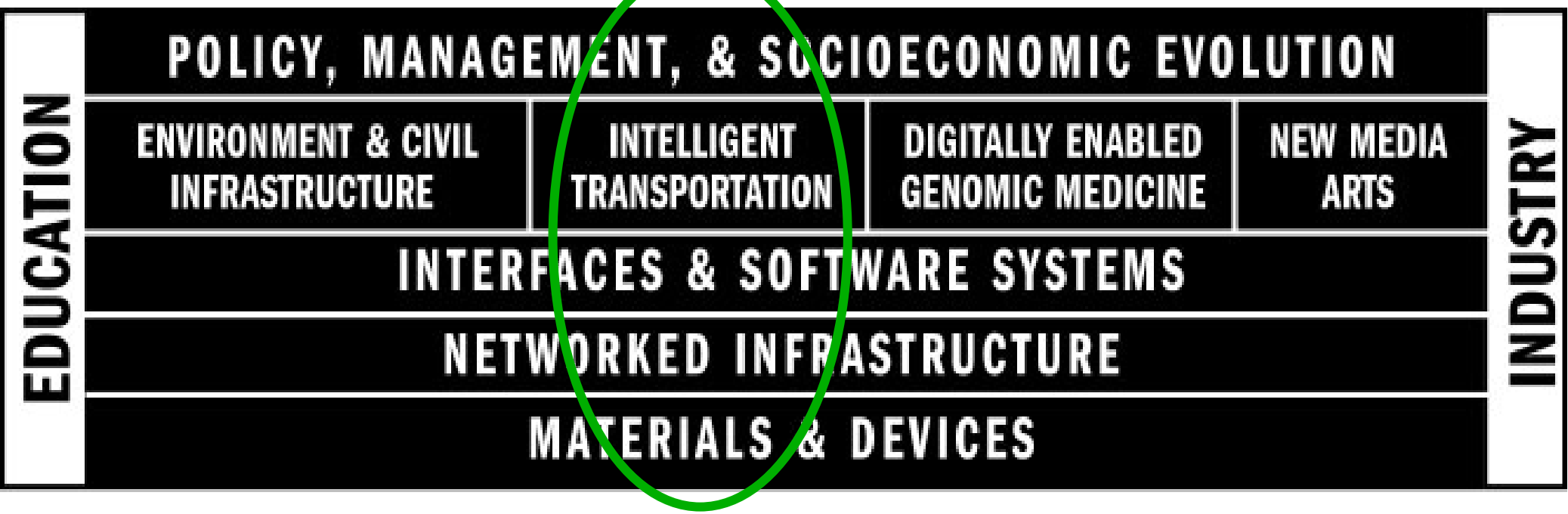
Calit2 is a University of California "Institutional Innovation" Experiment on How to Invent a Persistent Collaborative Research and Education Environment that Provides Insight into How the UC, a Major Research University, Might Evolve in the Future.

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Calit2--A Systems Approach to the Future of the Internet and its Transformation of Our Society

Calit2 Has Assembled a Complex Social Network
of Over 350 UC San Diego & UC Irvine Faculty
From Two Dozen Departments
Working in Multidisciplinary Teams
With Staff, Students, Industry, and the Community



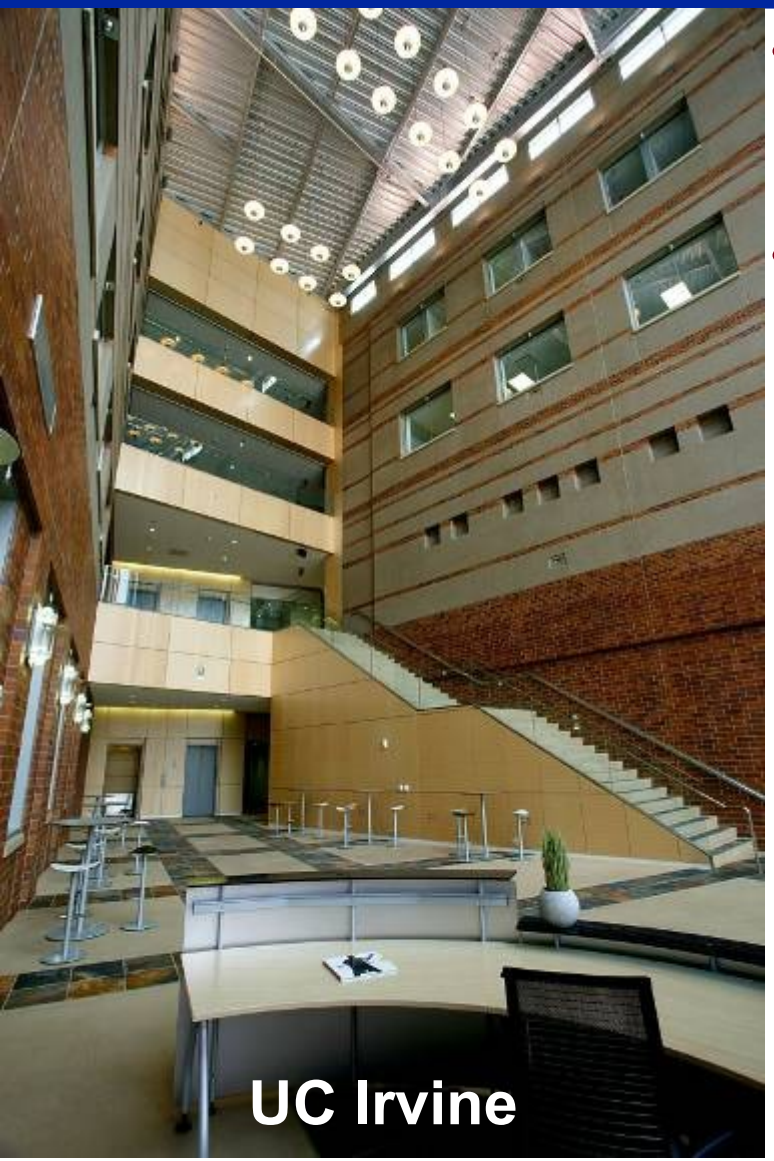
Integrating Technology Consumers and Producers
Into "Living Laboratories"

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www.calit2.net

it²

Two New Calit2 Buildings Provide New Laboratories for "Living in the Future"



- "Convergence" Laboratory Facilities
  - Nanotech, BioMEMS, Chips, Radio, Photonics
  - Virtual Reality, Digital Cinema, HDTV, Gaming
- Over 1000 Researchers in Two Buildings
  - Linked via Dedicated Optical Networks



www.calit2.net

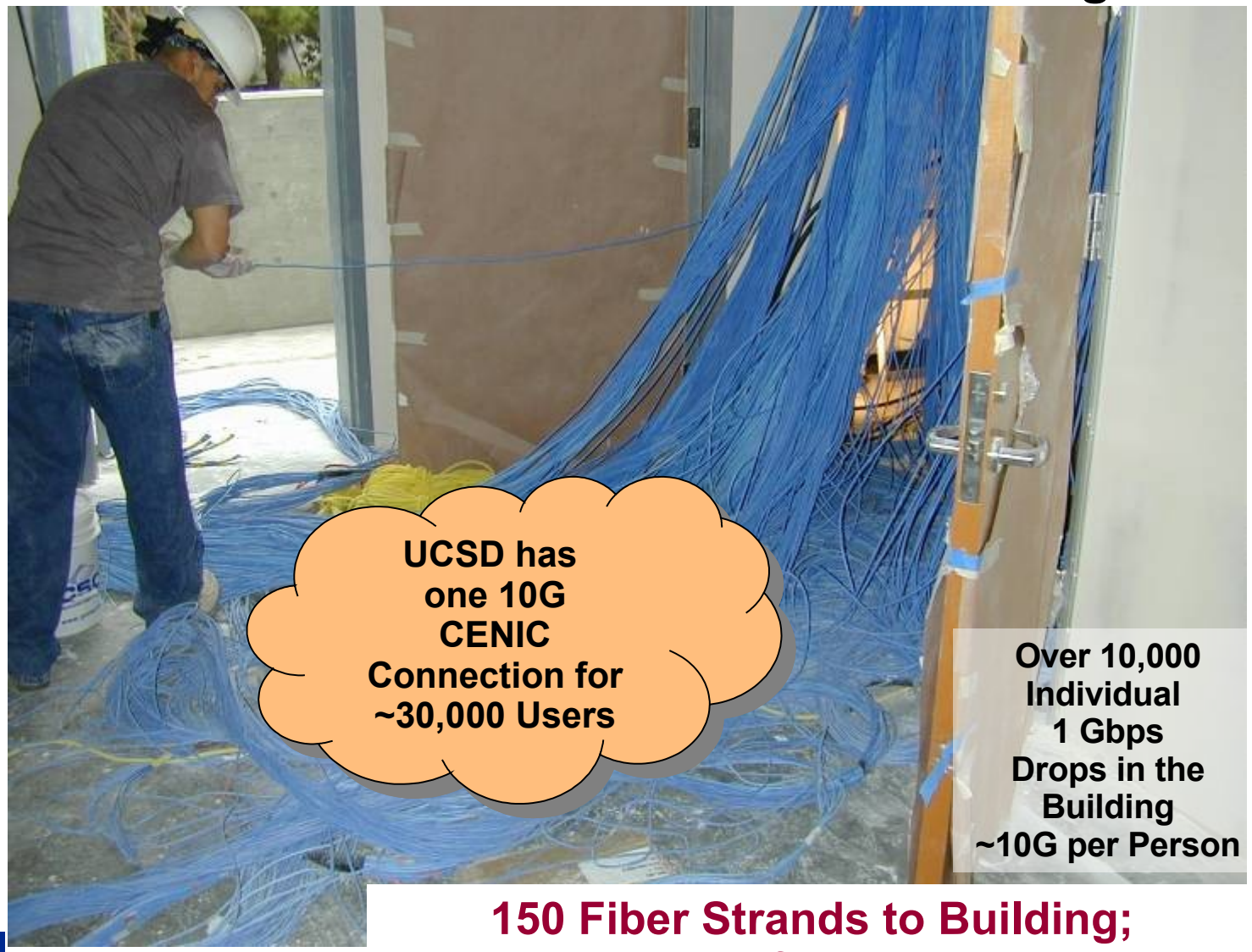
Preparing for a World in Which Distance is Eliminated…

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The Calit2@UCSD Building is Designed for Prototyping Extremely High Bandwidth Applications

1.8 Million Feet of Cat6 Ethernet Cabling



24 Fiber Pairs to Each Lab

150 Fiber Strands to Building; Experimental Roof Radio Antenna Farm Ubiquitous WiFi

Photo: Tim Beach, Calit2

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Data Intensive e-Science Instruments Require SuperNetworks for Data Transfer and Collaboration



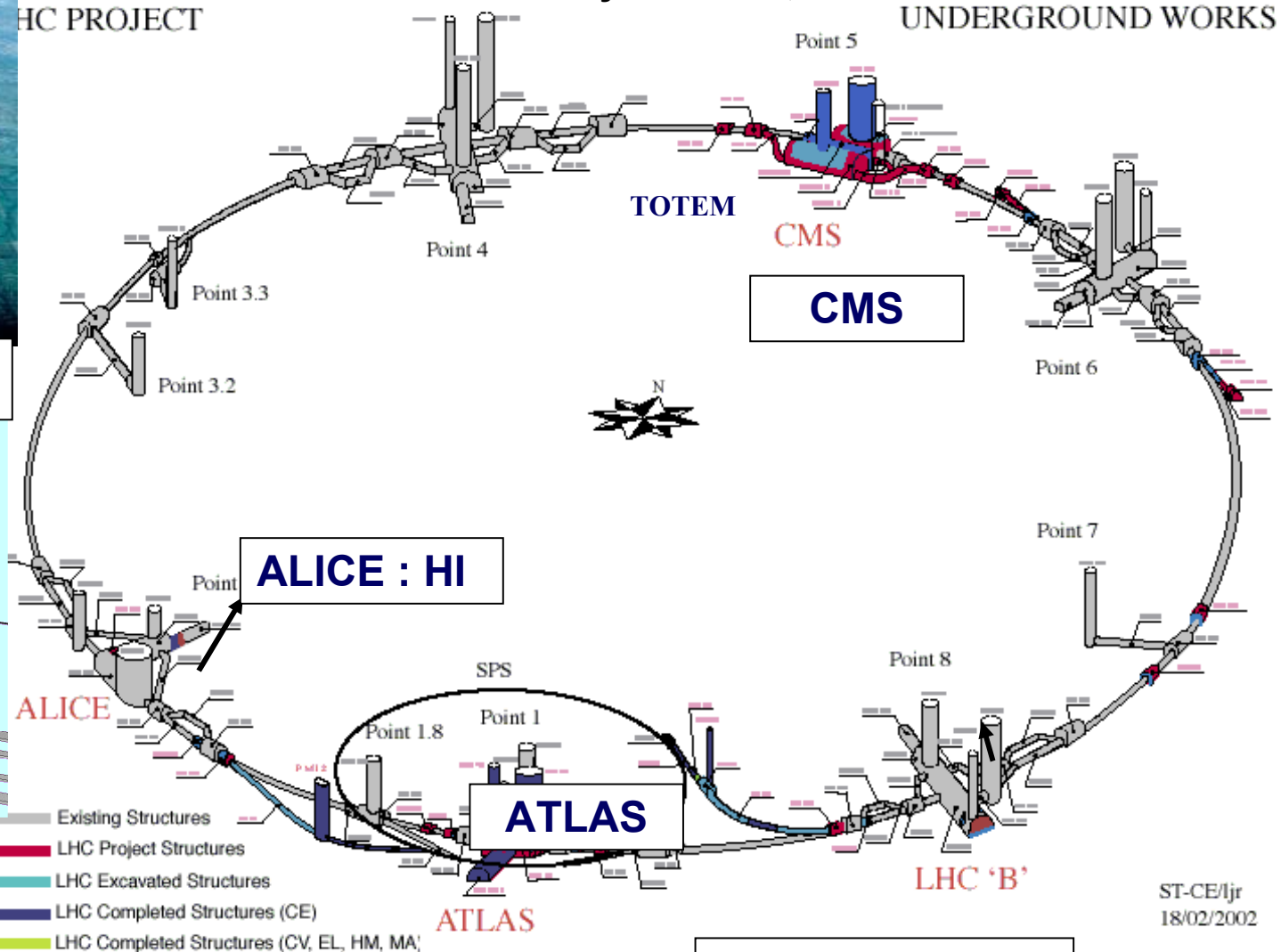
Large Hadron Collider (LHC): e-Science Driving Global Cyberinfrastructure

First Beams: April 2007 Physics Runs: Start in 2008

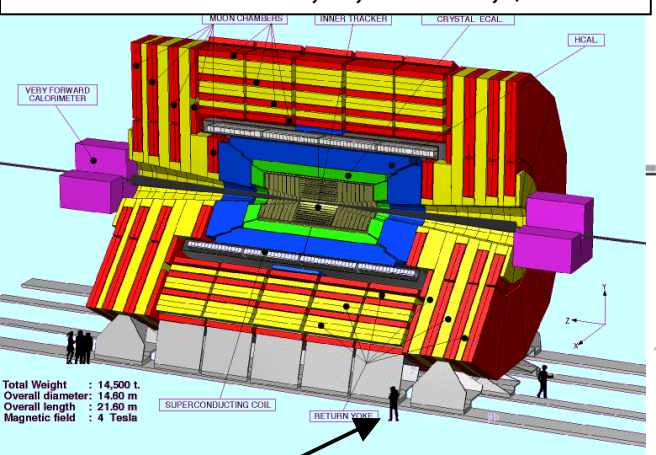


- pp $\sqrt{s}$ =14 TeV L=10^{34} cm^{-2} s^{-1}
- 27 km Tunnel in Switzerland & France

Source: Harvey Newman, Caltech



LHC CMS detector
15m X 15m X 22m,12,500 tons, $700M



human (for scale)

LHCb: B-physics

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High Energy and Nuclear Physics
A Terabit/s WAN by 2013!

Year	Production	Experimental	Remarks
2001	0.155	0.622-2.5	SONET/SDH
2002	0.622	2.5	SONET/SDH DWDM; GigE Integ.
2003	2.5	10	DWDM; 1 + 10 GigE Integration
2005-6	10-20	2-4 X 10	λ Switch; λ Provisioning
2007-8	30-40	~100 or 2 X 40 Gbps	1st Gen. λ Grids
2009-10	60-80	~5 X 40 or ~2 X 100	40 or 100 Gbps λ Switching
2011-12	~5 X 40 or ~2 X 100	~25 X 40 or ~10 X 100	2nd Gen λ Grids Terabit Networks
2013-14	~Terabit	~MultiTbps	~Fill One Fiber

Source:
Harvey
Newman,
Caltech

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The Unrelenting Exponential Growth of Data Requires an Exponential Growth in Bandwidth

- **"The Global Information Grid will need to store and access exabytes of data on a realtime basis by 2010"**
  - **Dr. Henry Dardy (DOD), Optical Fiber Conference, Los Angeles, CA USA, Mar 2006**

- **"Each LHC experiment foresees a recorded raw data rate of 1 to several PetaBytes/year"**
  - **Dr. Harvey Neuman (Cal Tech), Professor of Physics**

- **"US Bancorp backs up 100 TB financial data every night – now."**
  - **David Grabski (VP Information Tech. US Bancorp), Qwest High Performance Networking Summit, Denver, CO. USA, June 2006.**

- **"The VLA facility is now able to generate 700 Gbps of astronomical data and the Extended VLA will reach 3.2 Terabits per second by 2009."**
  - **Dr. Steven Durand, National Radio Astronomy Observatory, E-VLBI Workshop, MIT Haystack Observatory., Sep 2006.**

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Source: Jerry Sobieski MAX / University of Maryland

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A Simulation of Telepresence
Using Analog Communications to Prototype the Digital Future

"What we really have to do is eliminate distance between individuals who want to interact with other people and with other computers."
— Larry Smarr, Director, NCSA

- **Televisualization:**
  - **Telepresence**
  - **Remote Interactive Visual Supercomputing**
  - **Multi-disciplinary Scientific Visualization**







"We're using satellite technology…to demo what It might be like to have high-speed fiber-optic links between advanced computers in two different geographic locations."

— Al Gore, Senator
Chair, US Senate Subcommittee on Science, Technology and Space

ATT & Sun

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SIGGRAPH 1989

NCSA™

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The Bellcore VideoWindow -- A Working Telepresence Experiment



(1989)

"Imagine sitting in your work place lounge having coffee with some colleagues. Now imagine that you and your colleagues are still in the same room, but are separated by a large sheet of glass that does not interfere with your ability to carry on a clear, two-way conversation. Finally, imagine that you have split the room into two parts and moved one part 50 miles down the road, without impairing the quality of your interaction with your friends."

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Source: Fish, Kraut, and Chalfonte-CSCW 1990 Proceedings

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Caterpillar / NCSA: Distributed Virtual Reality for Global-Scale Collaborative Prototyping





NCSA™

Real Time Linked Virtual Reality and Audio-Video Between NCSA, Peoria, Houston, and Germany

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1996

www.sv.vt.edu/future/vt-cave/apps/CatDistVR/DVR.html

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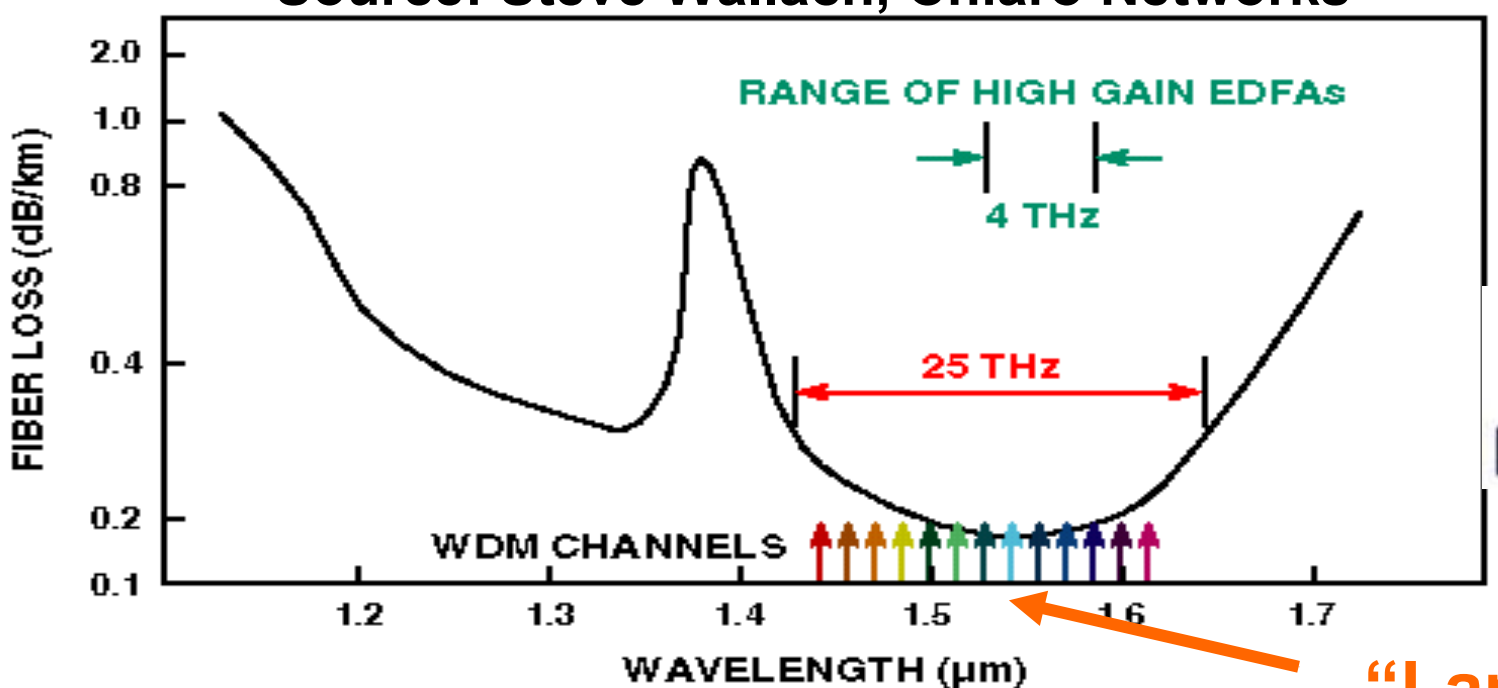
Dedicated Optical Channels Makes High Performance Cyberinfrastructure Possible

WAVELENGTH DIVISION MULTIPLEXING (WDM)

10 Gbps per User ~ 200x Shared Internet Throughput

- EXPLOITS
  - ENORMOUS BANDWIDTH OF SILICA FIBER
  - HIGH-GAIN WIDEBAND OPTICAL AMPLIFIERS

Source: Steve Wallach, Chiaro Networks



CHIARO

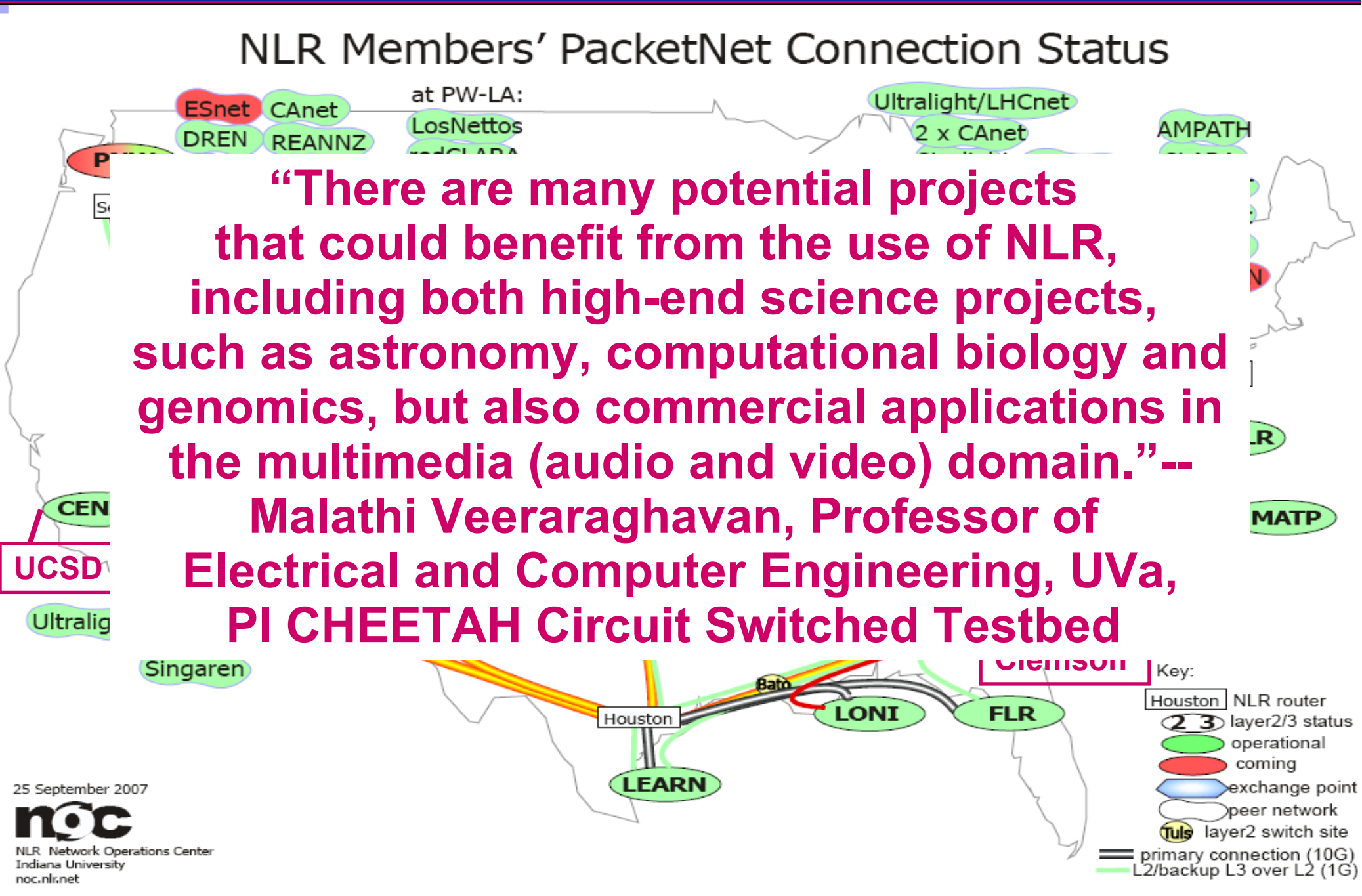
"Lambdas"

Parallel Lambdas are Driving Optical Networking The Way Parallel Processors Drove 1990s Computing

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National LambdaRail
Serves the University of Virginia



"There are many potential projects that could benefit from the use of NLR, including both high-end science projects, such as astronomy, computational biology and genomics, but also commercial applications in the multimedia (audio and video) domain."--
Malathi Veeraraghavan, Professor of Electrical and Computer Engineering, UVa, PI CHEETAH Circuit Switched Testbed

Calit2 Has Become a Global Hub for Optical Connections

Between University Research Centers at 10Gbps

Maxine Brown, Tom DeFanti, Co-Chairs

iGrid 2005

THE GLOBAL LAMBDA INTEGRATED FACILITY

www.igrid2005.org

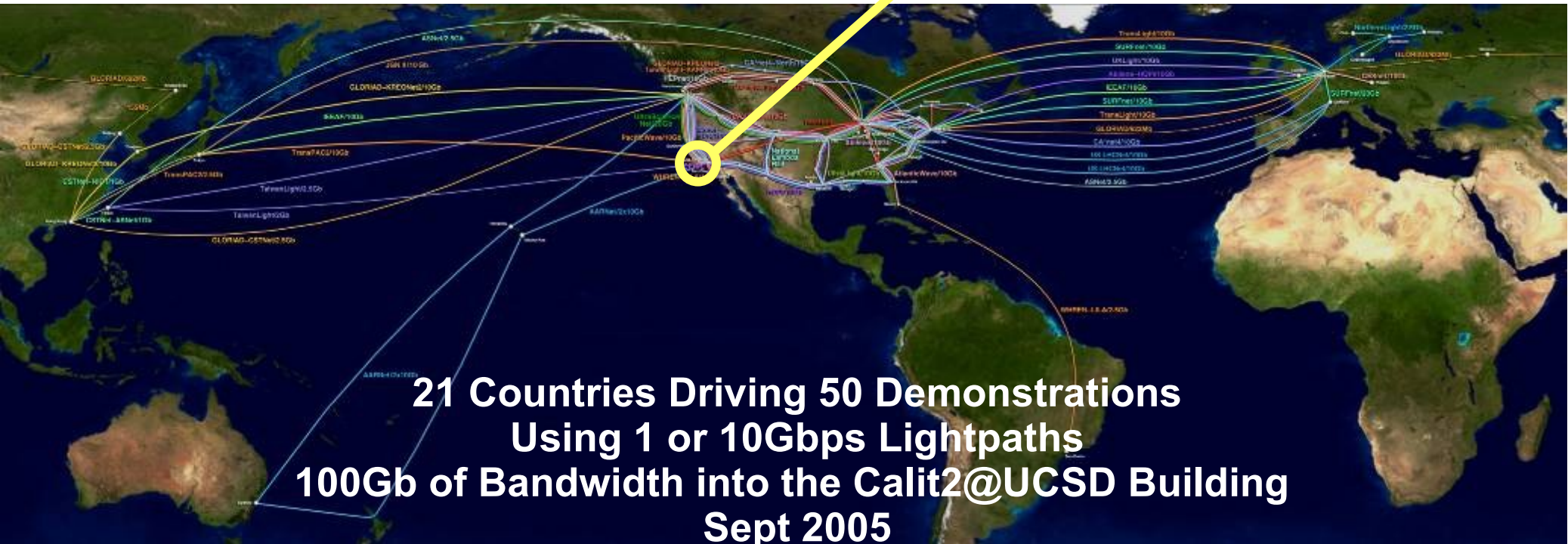


the UC Discovery Grant

September 26-30, 2005

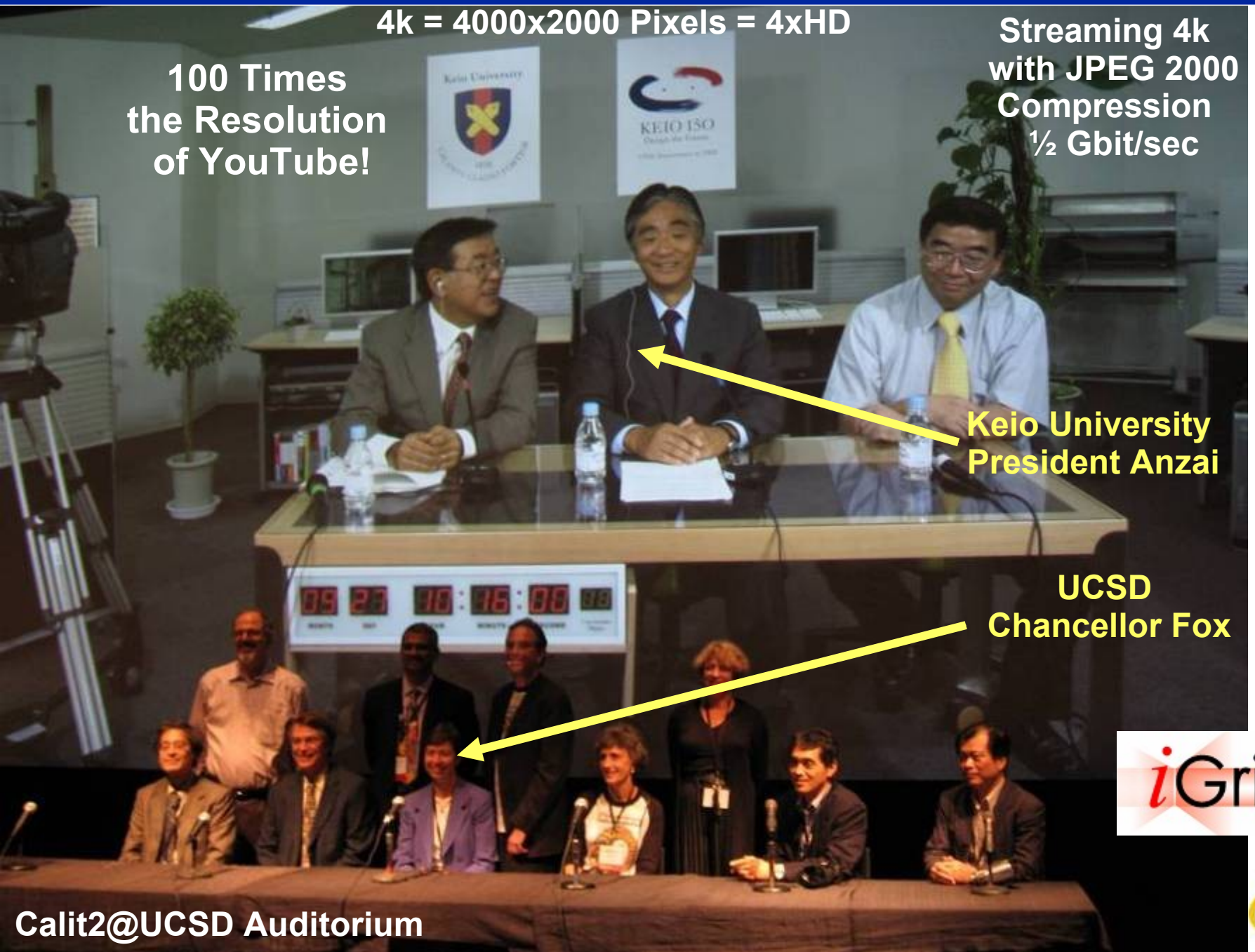
Calit2 @ University of California, San Diego

California Institute for Telecommunications and Information Technology



21 Countries Driving 50 Demonstrations
Using 1 or 10Gbps Lightpaths
100Gb of Bandwidth into the Calit2@UCSD Building
Sept 2005

iGrid Lambda Streaming Services: Telepresence Meeting Using Digital Cinema 4k Streams



CineGrid

Lays Technical Basis for Global Digital Cinema

Sony
NTT
SGI

iGrid 2005

it²

iGrid Lambda Data Services: Sloan Sky Survey Data Transfer

- **SDSS-I**
  - Imaged 1/4 of the Sky in Five Bandpasses
    - 8000 sq-degrees at 0.4 arc sec Accuracy
  - Detecting Nearly 200 Million Celestial Objects
  - Measured Spectra Of:
    - > 675,000 galaxies
    - 90,000 quasars
    - 185,000 stars

~200 GigaPixels!

iGRID2005
From Federal Express to Lambdas: Transporting Sloan Digital Sky Survey Data Using UDT
Robert Grossman, UIC

Transferred Entire SDSS (3/4 Terabyte) from Calit2 to Korea in 3.5 Hours—Average Speed 2/3 Gbps!



Sloan Digital Sky Survey



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www.sdss.org

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iGrid Lambda Control Plane Services: Transform Batch to Real-Time Global e-Very Long Baseline Interferometry



- Goal: Real-Time VLBI Radio Telescope Data Correlation
- Achieved 512Mb Transfers from USA and Sweden to MIT
- Results Streamed to iGrid2005 in San Diego

Optical Connections Dynamically Managed Using the DRAGON Control Plane and Internet2 HOPI Network

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Source: Jerry Sobieski, DRAGON

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iGrid Lambda Instrument Control Services– UCSD/Osaka Univ. Using Real-Time Instrument Steering and HDTV

Most Powerful Electron Microscope in the World -- Osaka, Japan





TS telescience project



HDTV

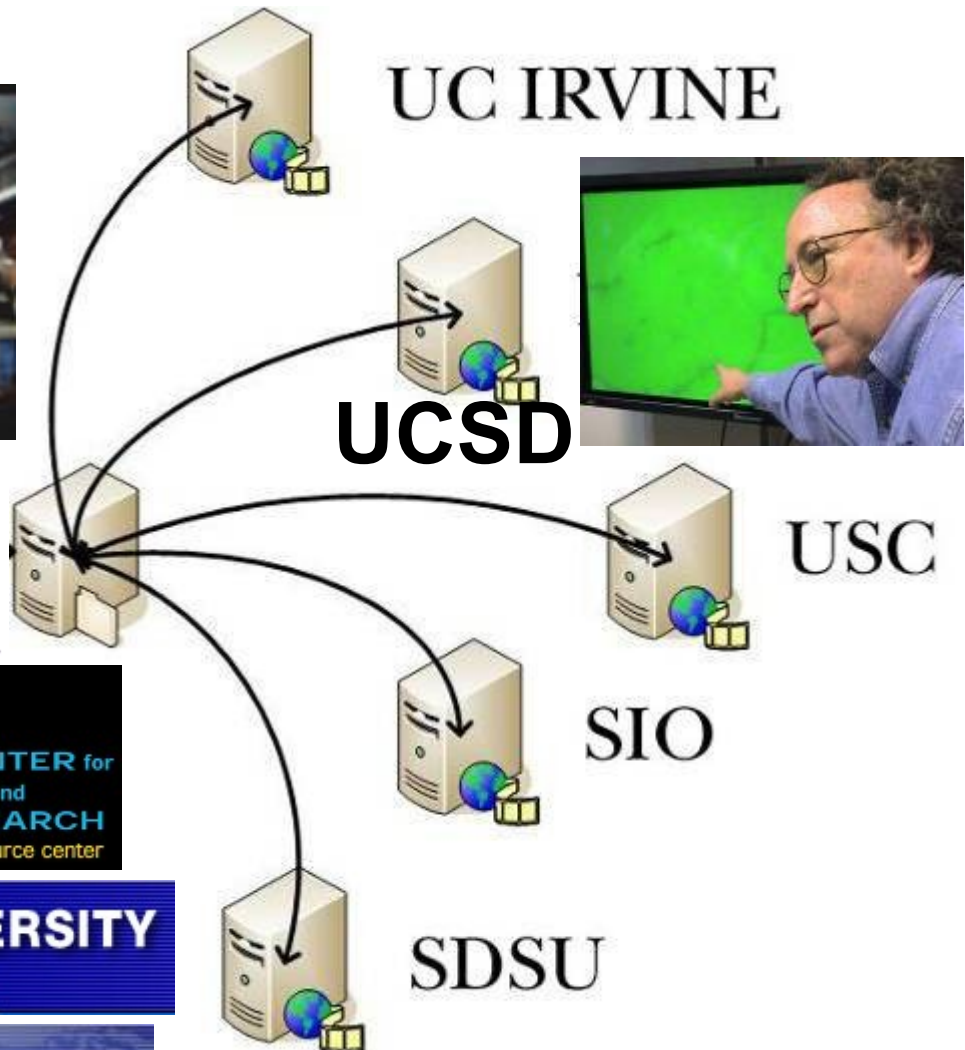
NBCR

NCMIR NATIONAL CENTER for MICROSCOPY and IMAGING RESEARCH at San Diego, an NIH supported resource center

OSAKA UNIVERSITY

KDDI GROUP KDDI Labs USA

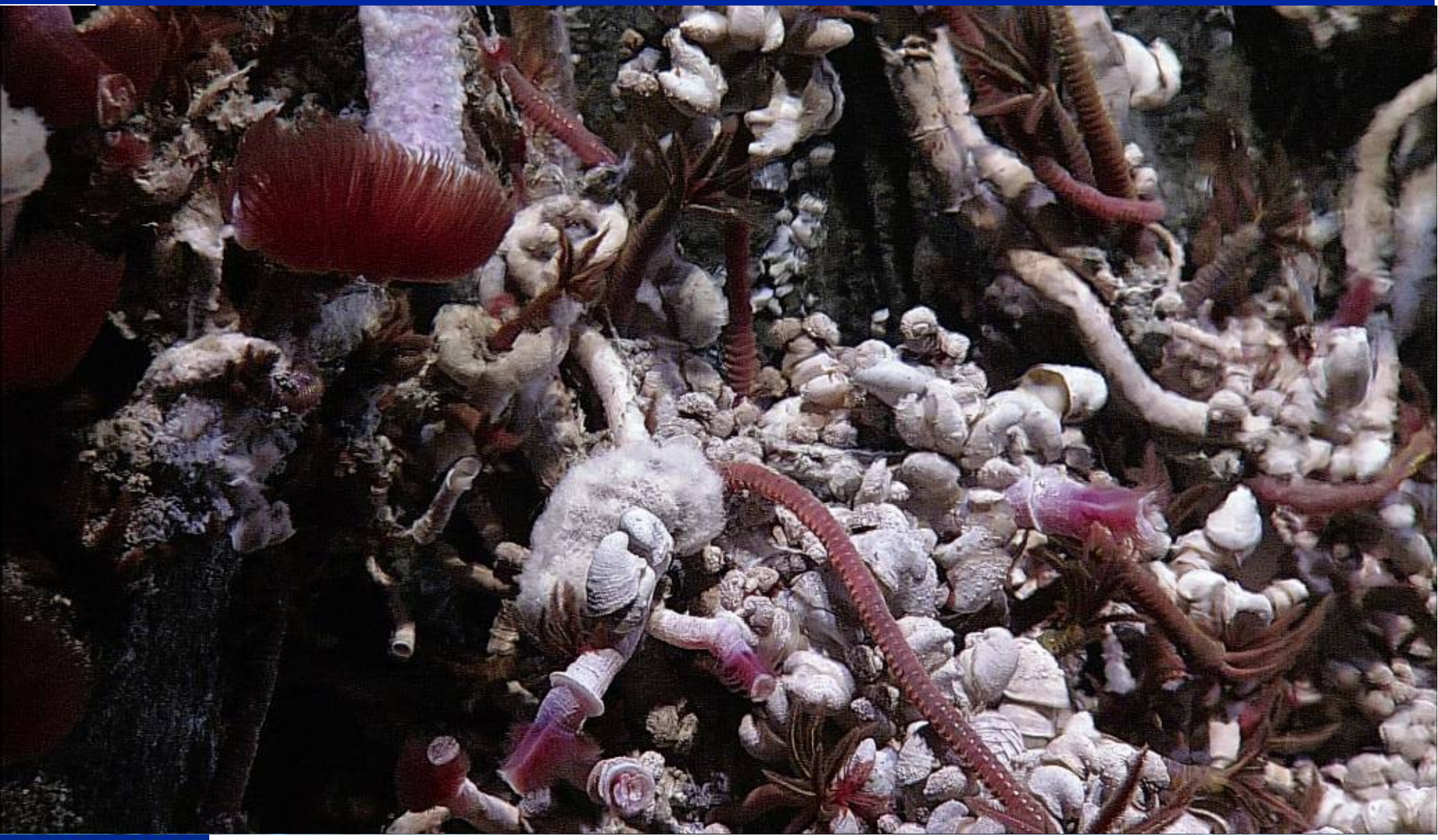
Southern California OptIPuter



Source: Mark Ellisman, UCSD

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iGrid Scientific Instrument Services: Enable Remote Interactive HD Imaging of Deep Sea Vent



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UCIrvine

Source John Delaney & Deborah Kelley, UWash

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Distributed Supercomputing: NASA MAP '06 System Configuration Using NLR



INTEL Corp
Portland, Oregon



NASA Ames
Mt. View, California



Northrop Grumman
McLean, Virginia



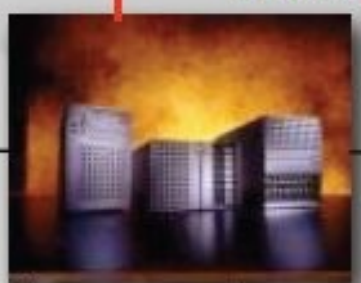
NASA Goddard
Greenbelt, Maryland

GEOS5 Forecast

WRF
(Regional Forecast)

NEXT-GENERATION NETWORKS
National Lambda Rail (10 - 40 Gb/s)

CISTO (GSFC) & GES DAAC DATA PORTALS



DATA PORTAL - CENTRAL ARCHITECTURAL ELEMENT
PORTAL PROVIDES INITIAL CONDITIONS FOR COMPUTE NODES, DATA FOR VISUALIZATION, SERVER FOR GDS OPERATIONS IN THE FIELD

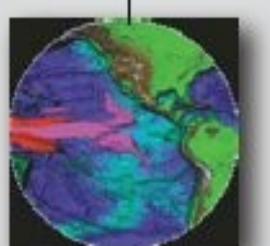
WMS Server

GrADS DODS





NOAA Data Portal (NOMADS)



NOAA

NASA African Monsoon Multidisciplinary Analyses (NAMMA)

FSU Meteorology

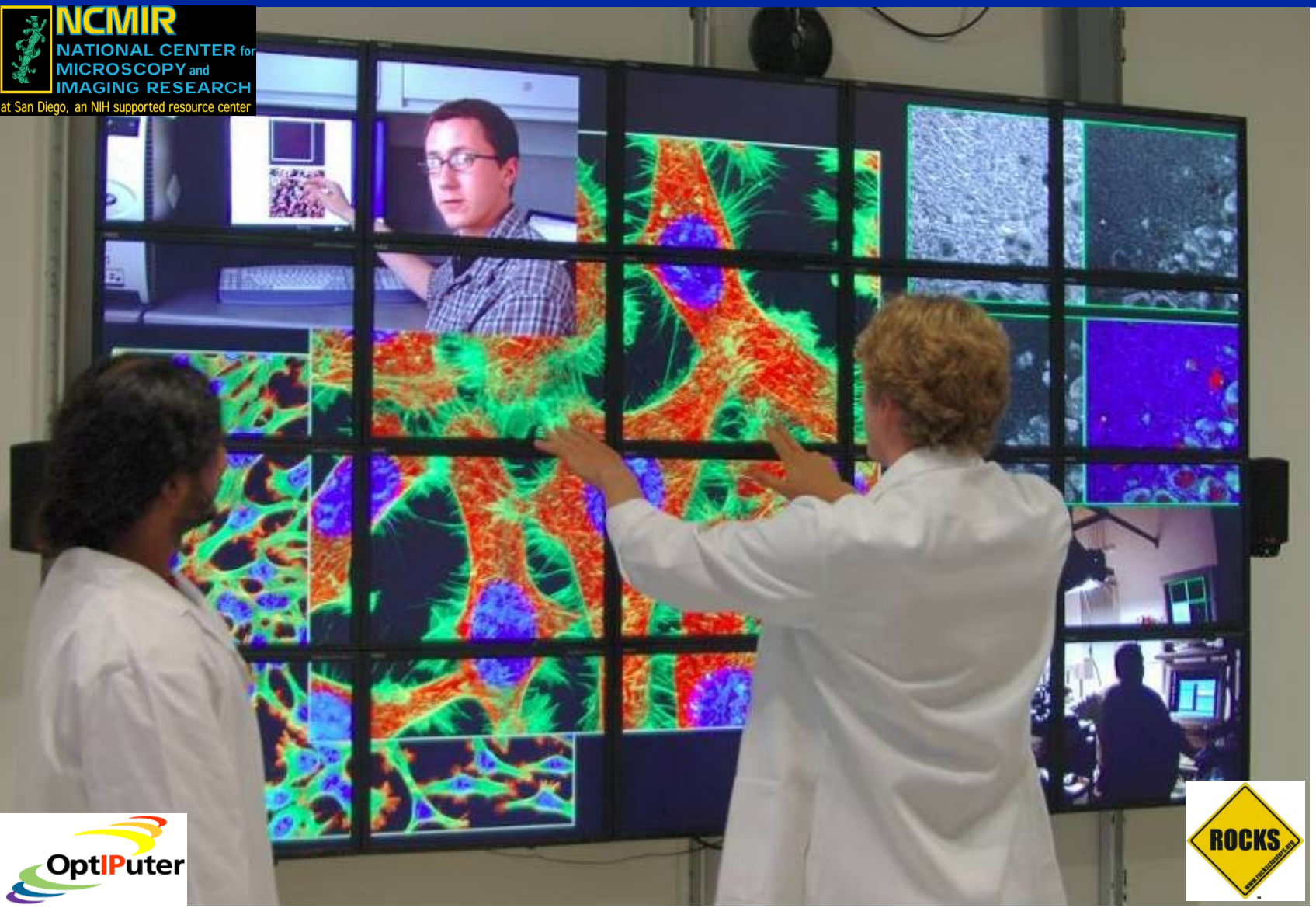
NASA

EXTERNAL COLLABORATORS

G. McConaughy (586), B. Womack (Northrop), P. Webster (606), D. Duffy (CSC), M. Whitehead (CSC), H. Mitchell (610.3), J. Delabeaujardiere (610.3), R. Jones (GST)

The OptIPuter Project: Creating High Resolution Portals Over Dedicated Optical Channels to Global Science Data

NCMIR
NATIONAL CENTER for MICROSCOPY and IMAGING RESEARCH
at San Diego, an NIH supported resource center



Scalable Adaptive Graphics Environment (SAGE)

evl electronic visualization laboratory

NSF

Now in Sixth and Final Year

Picture Source: Mark Ellisman, David Lee, Jason Leigh

OptIPuter

ROCKS

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Calit2 (UCSD, UCI) and UIC Lead Campuses—Larry Smarr PI
Univ. Partners: SDSC, USC, SDSU, NW, TA&M, UvA, SARA, KISTI, AIST
Industry: IBM, Sun, Telcordia, Chiaro, Calient, Glimmerglass, Lucent

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My OptIPortal™ – Affordable Termination Device for the OptIPuter Global Backplane

- 20 Dual CPU Nodes, 20 24” Monitors, ~$50,000
- 1/4 Teraflop, 5 Terabyte Storage, 45 Mega Pixels--Nice PC!
- Scalable Adaptive Graphics Environment (SAGE) Jason Leigh, EVL-UIC

evl electronic visualization laboratory





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Powered by Rocks ROCKS

Source: Phil Papadopoulos SDSC, Calit2

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The Calit2 Great Walls at UCSD and UCI Use CGLX and Are Now a Gbit/s HD Collaboratory



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OptIPortals Used to Visually Study Very Large Collages from NASA Space Observatories

CAMERA: Community Cyberinfrastructure for Advanced Marine Microbial Ecology Research and Analysis



Paul Gilna Ex. Dir.

National LambdaRail Direct Connect Computation and Storage Complex

PI Larry Smarr

Funded by: Gordon and Betty Moore Foundation

Joint Partnership of:

UCSD UCIrvine

Announced January 17, 2006--$24.5M Over Seven Years

Marine Genome Sequencing Project – Measuring the Genetic Diversity of Ocean Microbes



MARINE MICROBIOLOGY INITIATIVE

Gordon and Betty MOORE FOUNDATION

Sorcerer II Data Will Double Number of Proteins in GenBank!

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J. Craig Venter INSTITUTE

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Calit2's Direct Access Core Architecture Has Created Next Generation Metagenomics Server

Gordon and Betty MOORE FOUNDATION

Sargasso Sea Data

Sorcerer II Expedition (GOS)

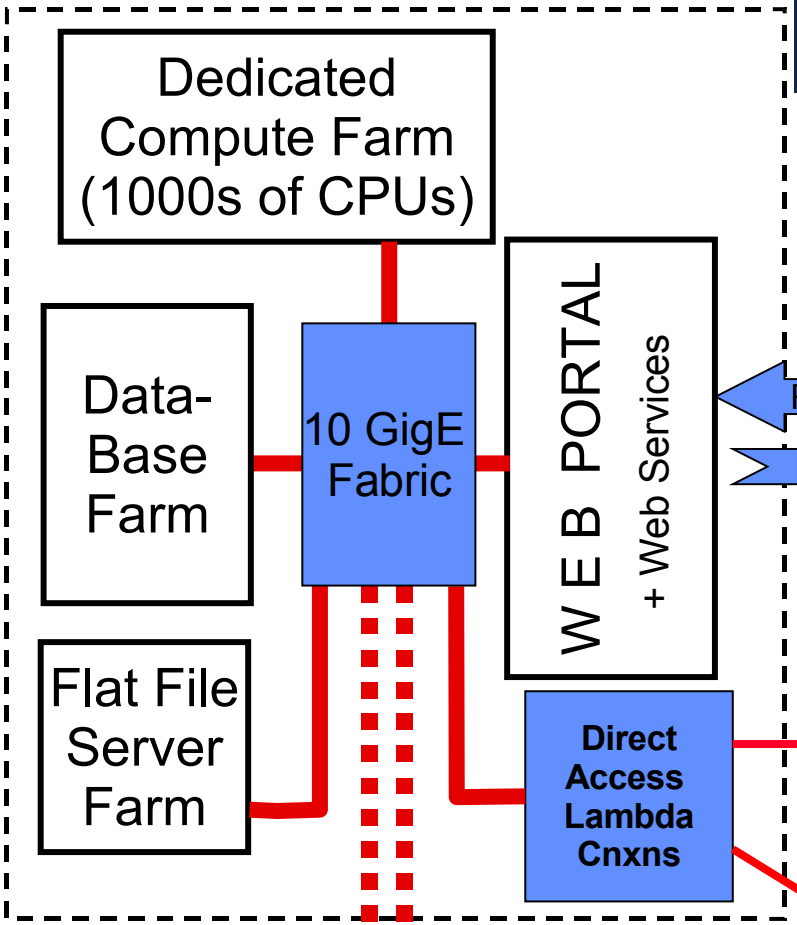
JGI Community Sequencing Project

Moore Marine Microbial Project

NASA and NOAA Satellite Data

Community Microbial Metagenomics Data

Powered by Rocks



Source: Phil Papadopoulos, SDSC, Calit2

CENTER FOR EARTH OBSERVATIONS & APPLICATIONS

SCRIPPS INSTITUTION OF OCEANOGRAPHY

SDSC SAN DIEGO SUPERCOMPUTER CENTER

UCSD UCIrvine

J. Craig Venter INSTITUTE

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OptIPlanet Collaboratory Persistent Infrastructure Between Calit2 and U Washington



OptIPuter

Ginger Armbrust's Diatoms: Micrographs, Chromosomes, Genetic Assembly

ROCKS







UW's Research Channel
Michael Wellings

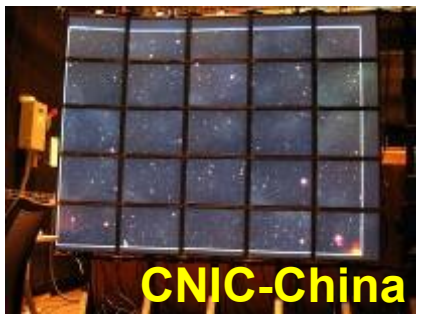
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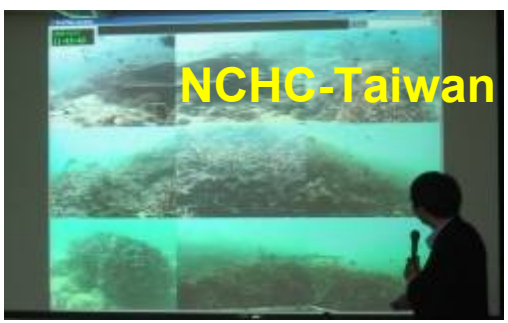
OptIPortals
Are Being Adopted Globally


AIST-Japan


Osaka U-Japan


KISTI-Korea


CNIC-China


NCHC-Taiwan


UZurich


SARA- Netherlands


Brno-Czech Republic


EVL@UIC


Calit2@UCSD


Calit2@UCI

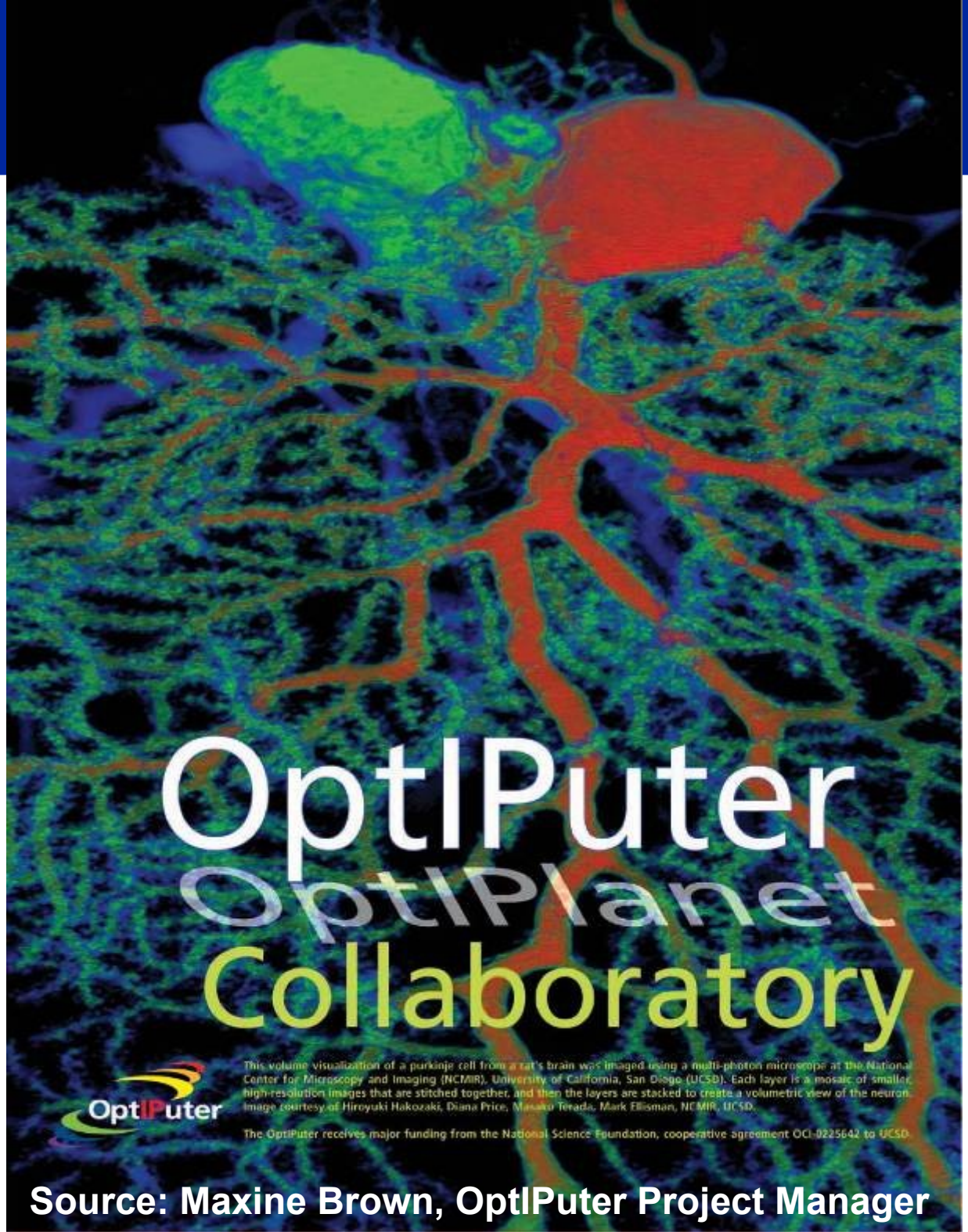

NCMIR@UCSD

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Powered by Rocks ROCKS

evl electronic visualization laboratory

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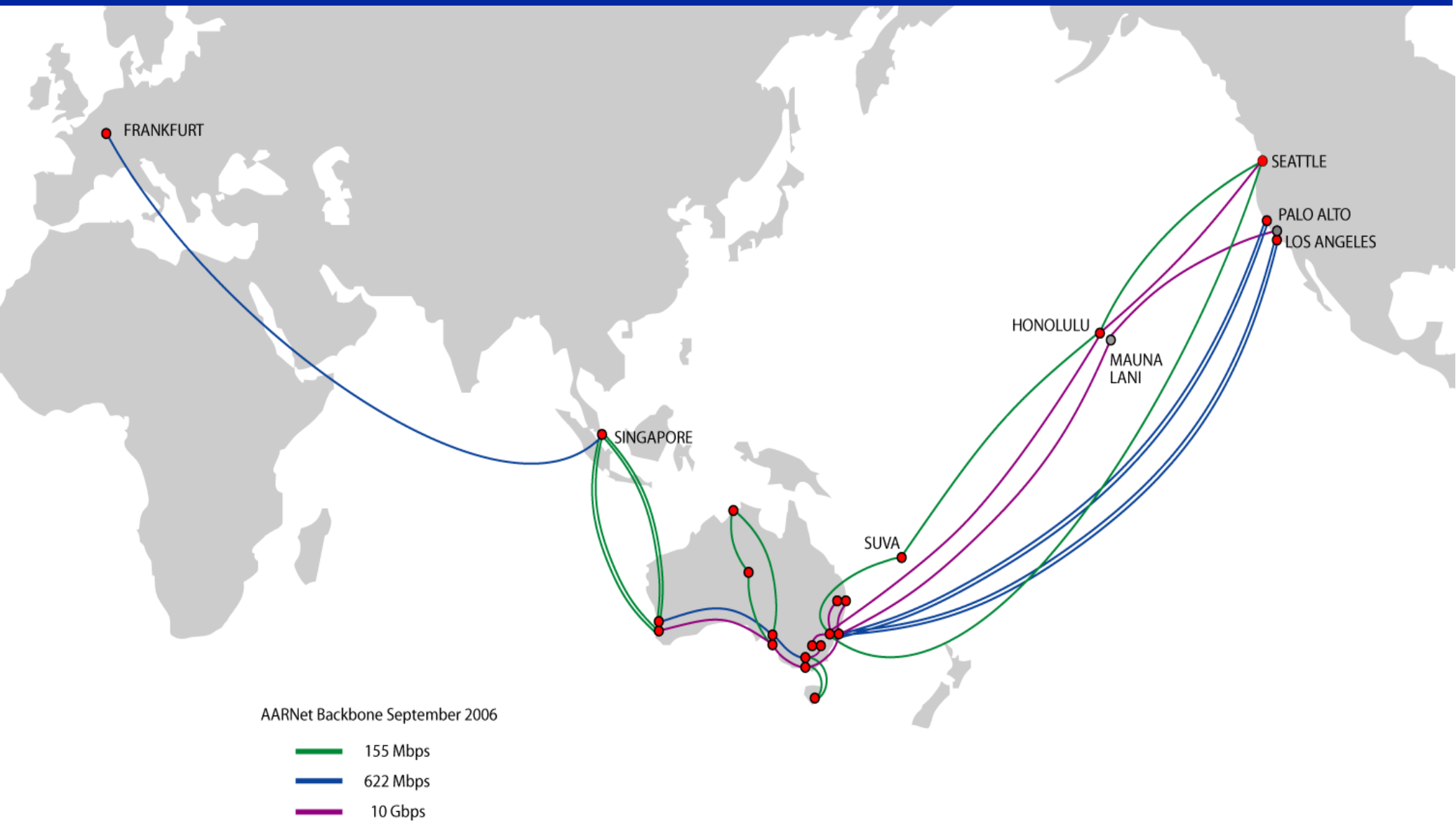
Source: Maxine Brown, OptIPuter Project Manager

Green Initiative:

Can Optical Fiber Replace Airline Travel for Continuing Collaborations ?

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AARNet International Network



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Launch of the 100 Megapixel OzIPortal Over Qvidium Compressed HD on 1 Gbps CENIC/PW/AARNet Fiber



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ROCKS

January 15, 2008

OptIPuter

www.calit2.net/newsroom/release.php?id=1219

Protein Visualizations on OzIPortal
Created with Covise Software Displayed with CGLX



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Covise, Phil Weber, Jurgen Schulze, Calit2
CGLX, Kai-Uwe Doerr , Calit2
www.calit2.net/newsroom/release.php?id=1219

Victoria Premier and Australian Deputy Prime Minister Asking Questions



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www.calit2.net/newsroom/release.php?id=1219

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University of Melbourne Vice Chancellor Glyn Davis in Calit2 Replies to Question from Australia



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"Using the Link to Build the Link" Being Extended to Monash Univ., UQ, CSIRO…

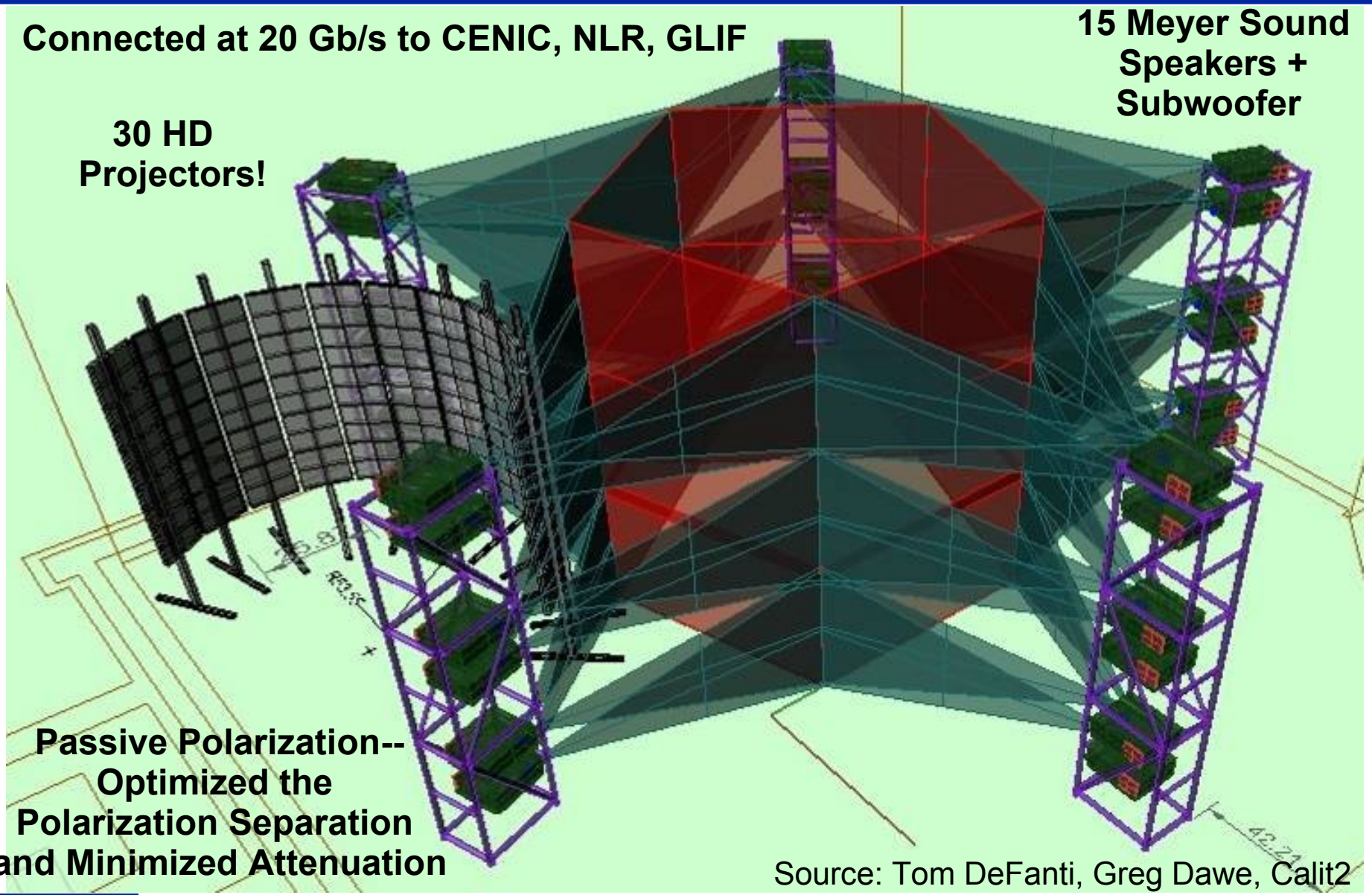


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No Calit2 Person Physically Flew to Australia to Bring This Up!

www.calit2.net/newsroom/release.php?id=1219

3D OptIPortals: Calit2 StarCAVE and Varrier: Enables Exploration of Virtual Worlds



Cluster with 30 Nvidia 5600 cards-60 GB Texture Memory

The StarCAVE as a “ Browser” for the NASA’s “Blue Marble” Earth Dataset

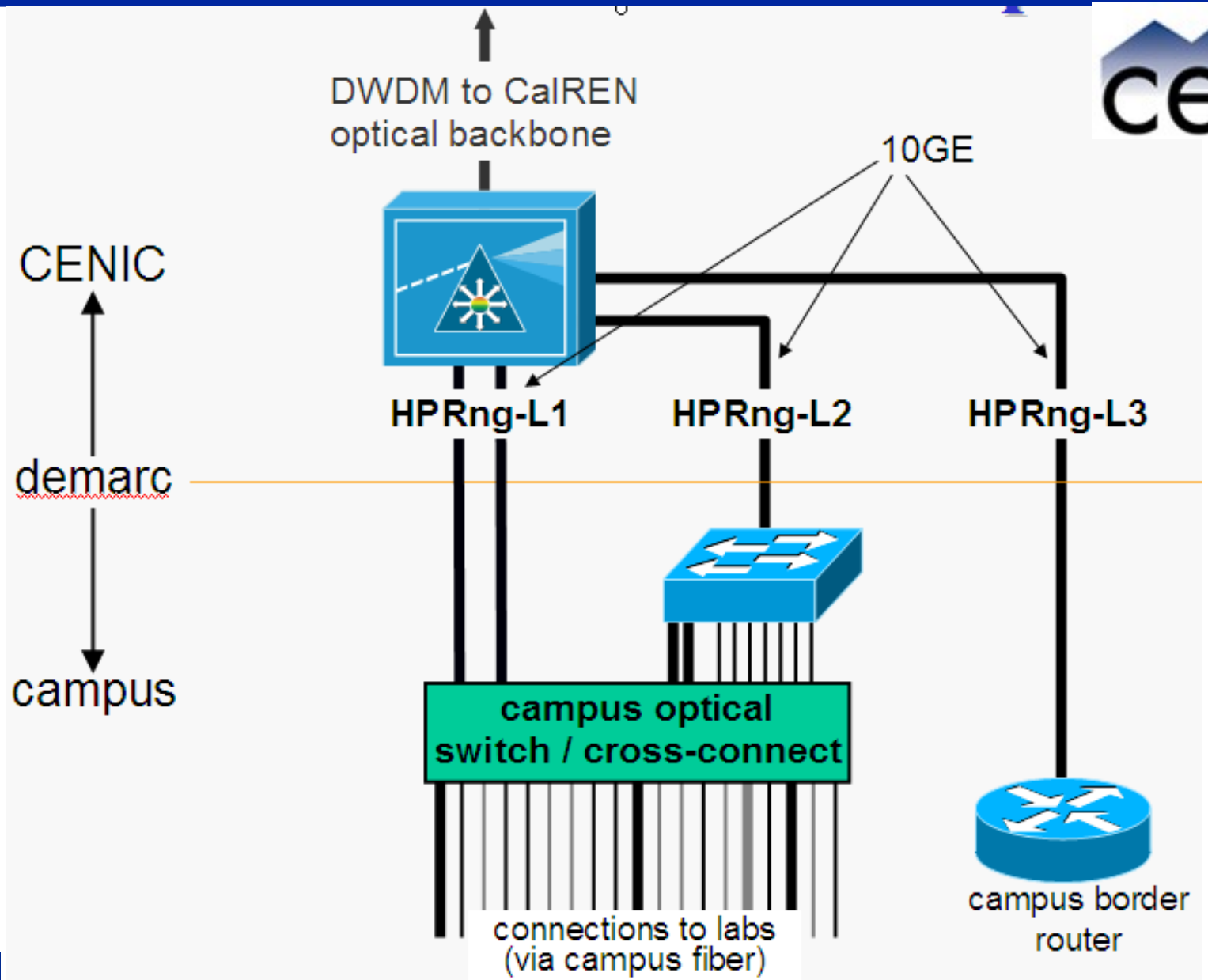


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Source: Tom DeFanti, Jurgen Schulze, Bob Kooima, Calit2/EVL

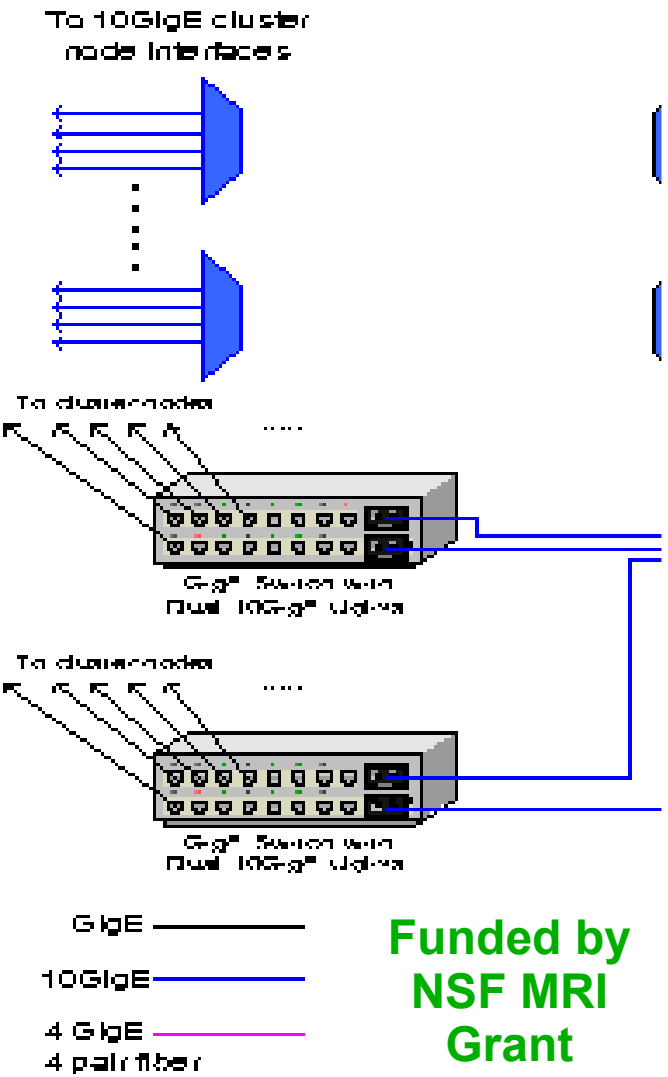
it²

Campus Preparations Needed to Accept NLR Handoff



Source: Jim Dolgonas, CENIC

Current UCSD Experimental Optical Core: Ready to Couple to CENIC L1, L2, L3 Services

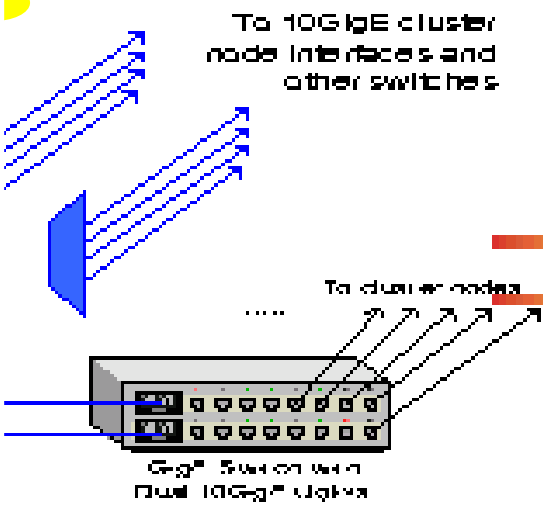


Goals by 2008:

- >= 50 endpoints at 10 GigE
- >= 32 Packet switched
- >= 32 Switched wavelengths
- >= 300 Connected endpoints

Approximately 0.5 TBit/s Arrive at the "Optical" Center of Campus
Switching will be a Hybrid Combination of:
Packet, Lambda, Circuit -- OOO and Packet Switches Already in Place

CENIC L1, L2 Services



CalREN-HPR Research Cloud

Campus Research Cloud

Funded by NSF MRI Grant

OptIPuter Border Router

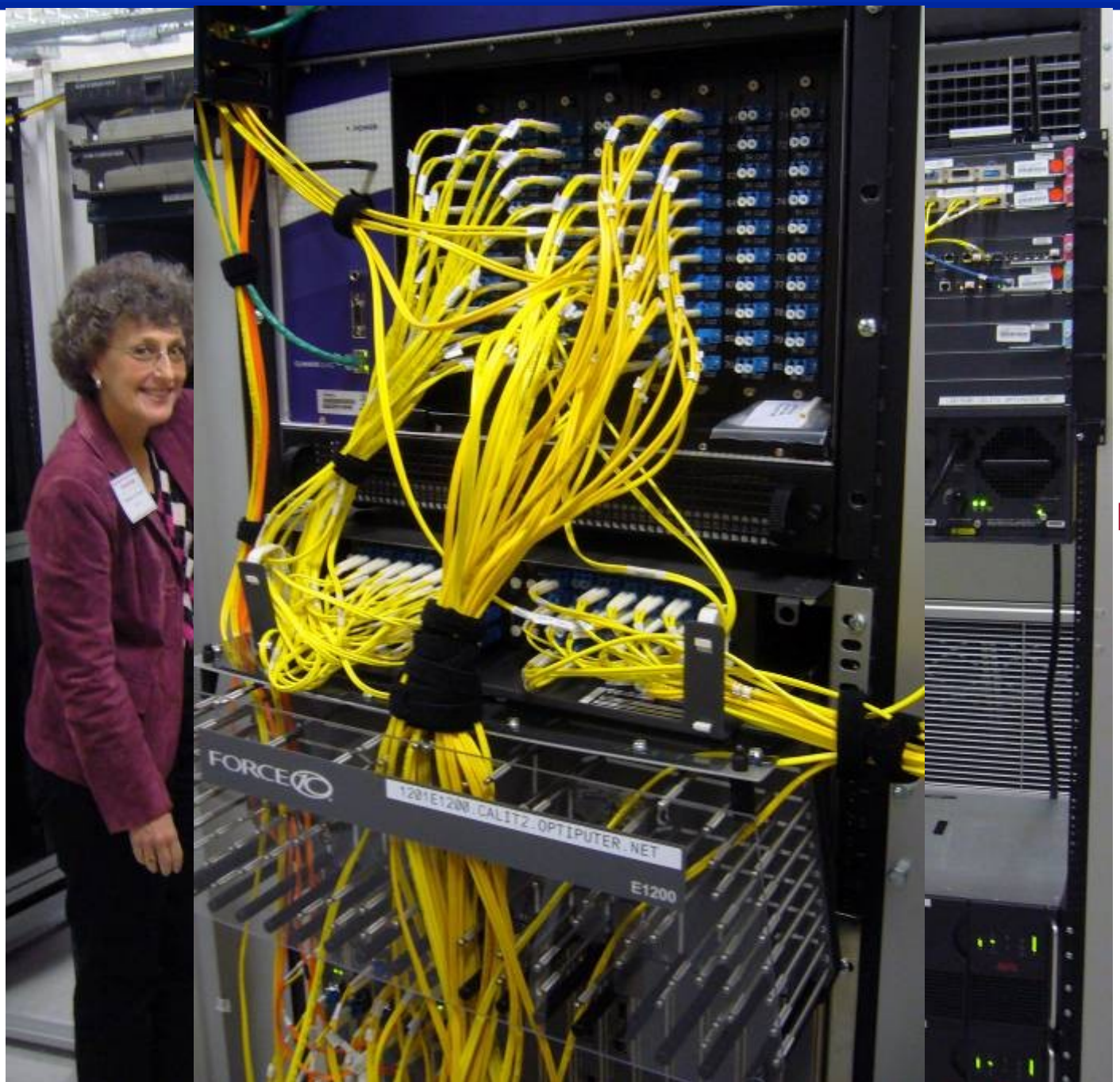
Source: Phil Papadopoulos, SDSC/Calit2 (Quartzite PI, OptIPuter co-PI)

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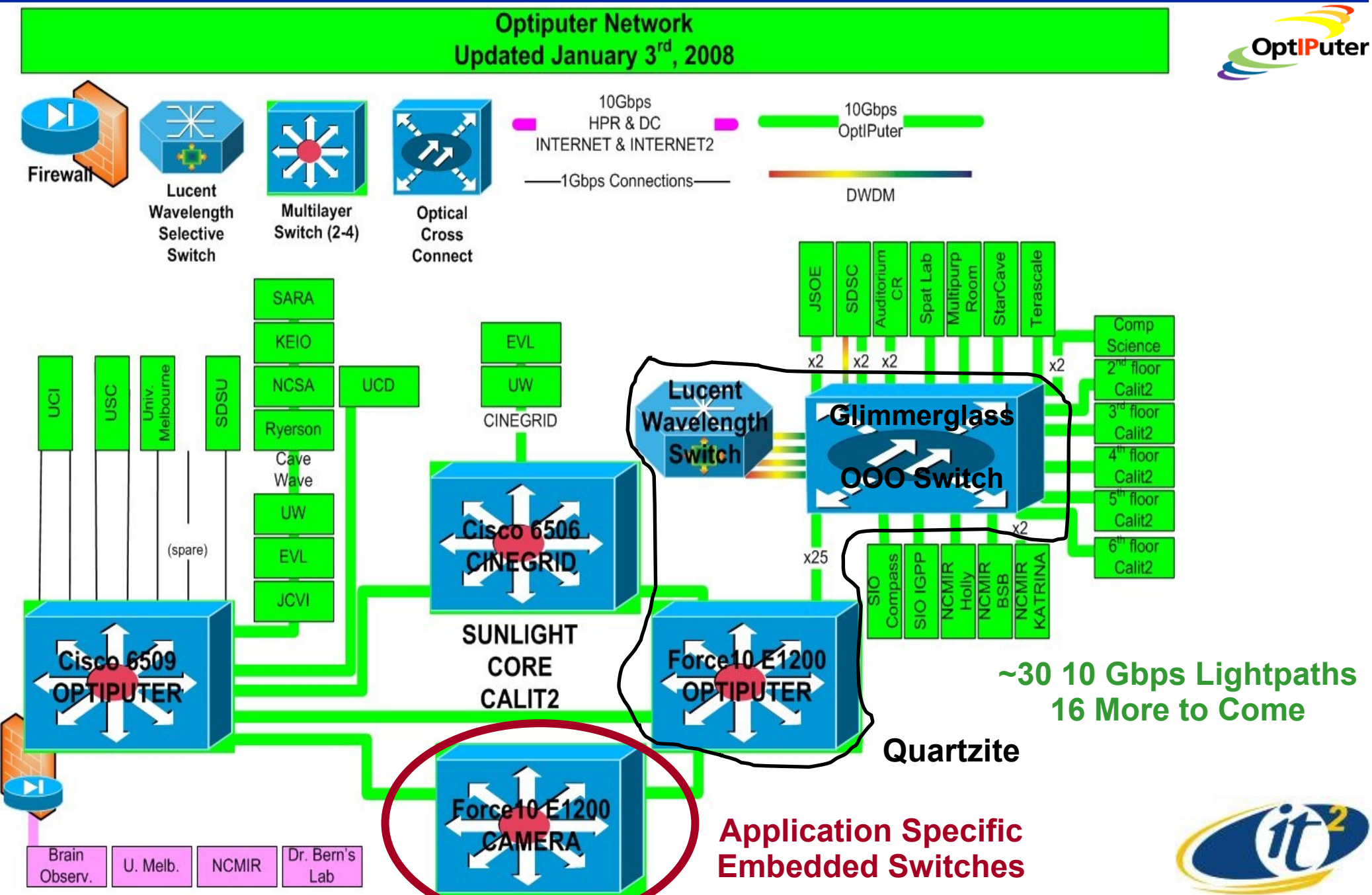
Calit2 Sunlight
Optical Exchange Contains Quartzite



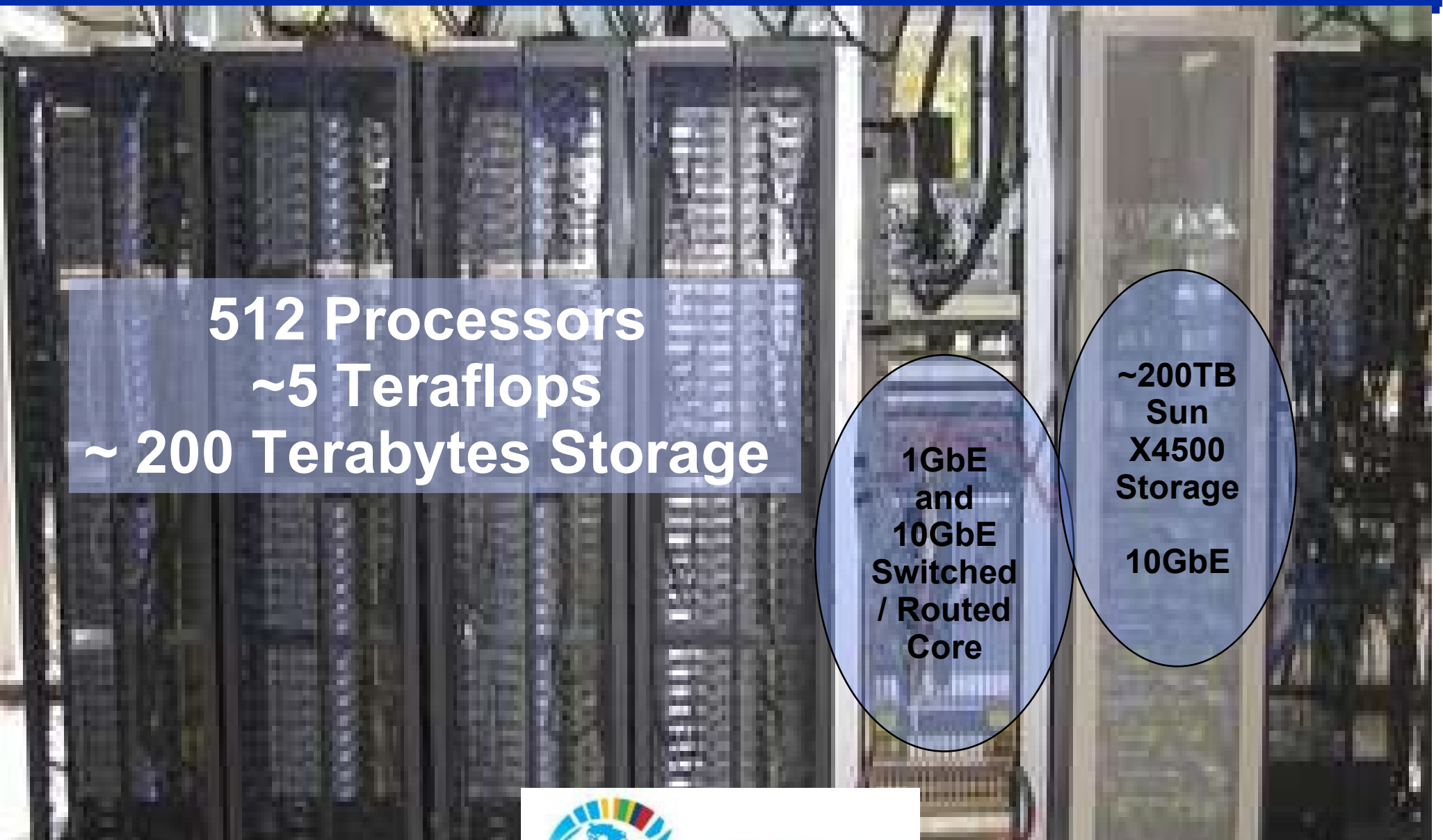
10:45 am
Feb. 21, 2008

UCSD
UCIrvine

Block Layout of Quartzite/OptIPuter Network



Calit2 Microbial Metagenomics Cluster Production System



UCSD UCIrvine SDSC ROCKS camera Marine Microbial Ecology J. Craig Venter INSTITUTE it²

Beyond Cloud Computing-- LambdaGrid Computational Science

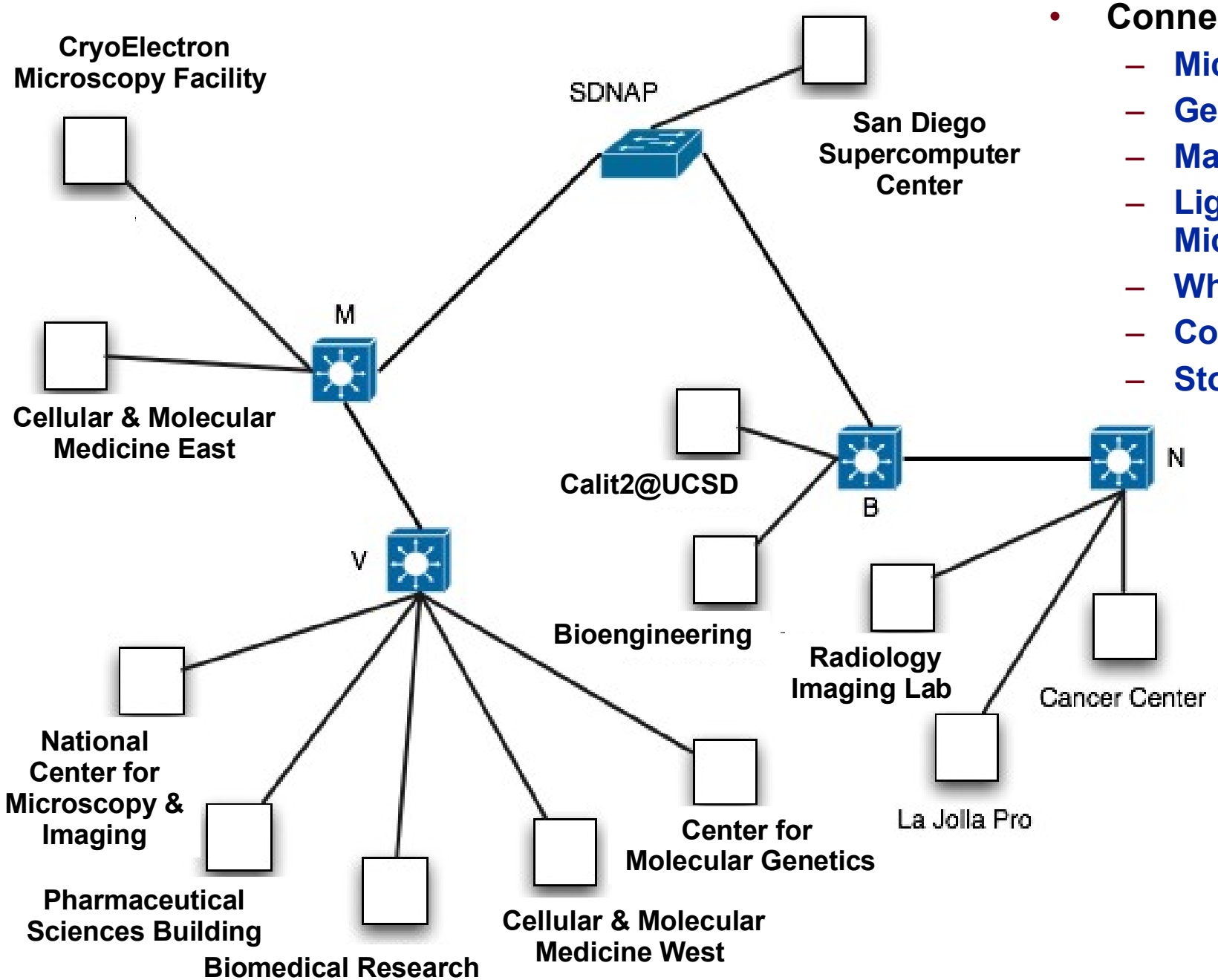
- **Computational Challenge**
  - Needed to Run a Large Number of Pre-computed BLAST Sequence Alignments for JCVI Fragment Recruitment Viewer (FRV)
  - CAMERA Development and Batch Clusters Oversubscribed
  - Had Spare Capacity in SDSC Cluster Connected to Quartzite
- **LambdaGrid Solution**
  - Reconfigure Private Side of Network to "Attach" Nodes in SDSC Rockstar Cluster to CAMERA Ikelite Cluster for Batch Processing
    - Direct Network Connection to CAMERA X4500 Thumper Storage
    - No Changes to Application Software or Paths
    - Rockstar Nodes Reconfigured to Support FRV Needs
  - Rockstar (SDSC) Nodes Integrated as Part of Ikelite (Calit2) Batch System
    - ~2000 CPU-Days Dedicated Computing over Previous 14 Days
    - O(2TB) of Output
    - Running Right Now

UCSD UCIrvine SDSC

Source:Phil Papadopoulos, SDSC/Calit2
(Quartzite PI, OptIPuter co-PI)

OptIPuter ROCKS it2

UCSD Optical Networked Biomedical Researchers and Instruments—a LambdaGrid "Data Utility"



- **Connects at 10 Gbps :**
  - **Microarrays**
  - **Genome Sequencers**
  - **Mass Spectrometry**
  - **Light and Electron Microscopes**
  - **Whole Body Imagers**
  - **Computing**
  - **Storage**

Optically Connected "Green" Modular Datacenters
UCSD Installing Two Sun Microsystems Boxes



Sun Black Box Container



7 Racks plus Network



Takes up 2 Parking Spaces



Data Power Cooling

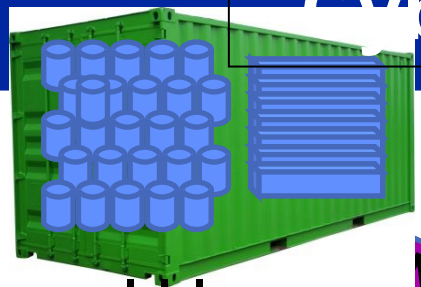
UCSD Jacobs School of Engineering

UCSD Structural Engineering Dept. Conducted Tests May 2007

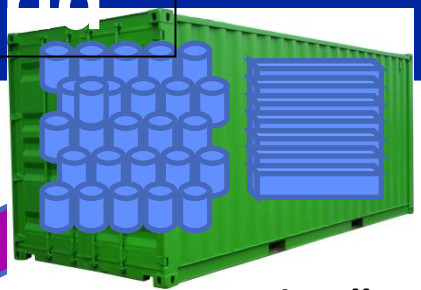
UCSD UCIrvine

it²

Planned UCSD Research Cyberinfrastructure LambdaGrid



Active Data Replication



Eco-Friendly
Storage and Compute

V x 10 Gbit

N x 10 Gbit

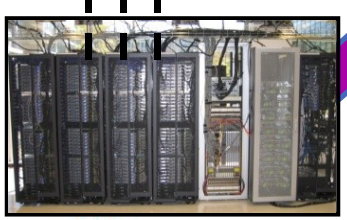


10 Gigabit
L2/L3 Switch

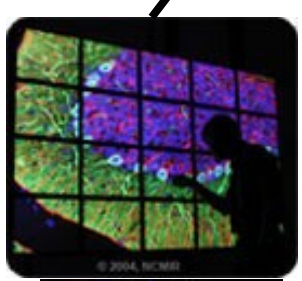
"Network in a box"
- > 200 Connections
- DWDM or Gray Optics

Wide-Area 10G
- Cenic/HPR
- NLR Cavewave
- Cinegrid
- …

On-Demand Physical Connections



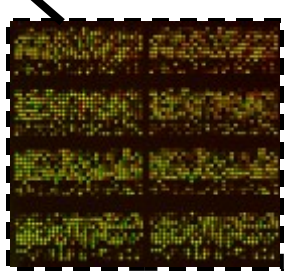
camera
Marine Microbial Ecology



NCMIR
NATIONAL CENTER for MICROSCOPY and IMAGING RESEARCH



NBCR



Microarray

Your Lab Here

OptIPuter

UCSD
UCIrvine

ROCKS

Source:Phil Papadopoulos, SDSC/Calit2

it2