# How Global-Scale Personal Lightwaves are Transforming Scientific Research

University of Virginia Computational Science Speaker Series
University of Virginia Library
October 17, 2007

**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**

UCSD
UCIrvine

it²

# 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. These lambdas enable the Grid program to be completed, in that they add the network elements to the compute and storage elements which can be discovered, reserved, and integrated by the Grid middleware to form global LambdaGrids. These user controlled 1- or 10- Gbps lambdas are providing 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 to create dedicated lightpaths across and beyond campuses, in addition to traditional shared Internet networks. I will describe how these user configurable LambdaGrid "metacomputer" global platforms open new frontiers in in collaborative work environments, digital cinema, interactive ocean observatories, and marine microbial metagenomics.

UCSD
UCIrvine

# Data Intensive e-Science Instruments Will Require SuperNetworks




UCSD
UCIrvine

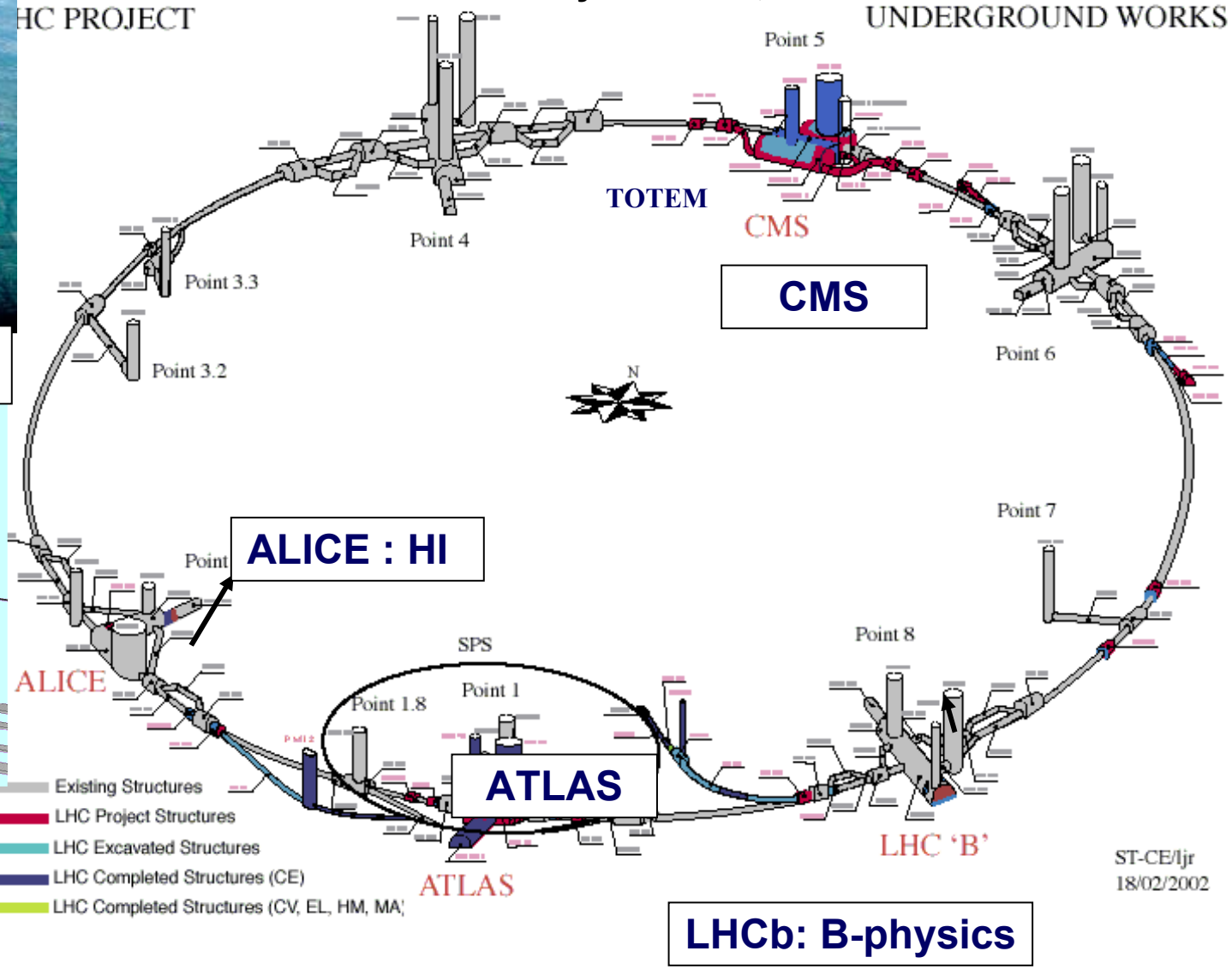
# Large Hadron Collider (LHC): e-Science Driving Global Cyberinfrastructure

**First Beams: April 2007 Physics Runs: Start in 2008**

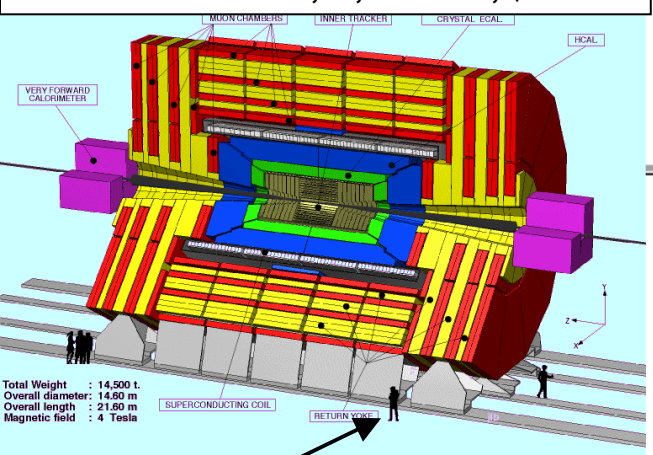


- pp $\sqrt{s}$ =14 TeV L=$10^{34}$ cm$^{-2}$ s$^{-1}$
- 27 km Tunnel in Switzerland & France

Source: Harvey Newman, Caltech




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




human (for scale)

**LHCb: B-physics**

UCSD
UCIrvine

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

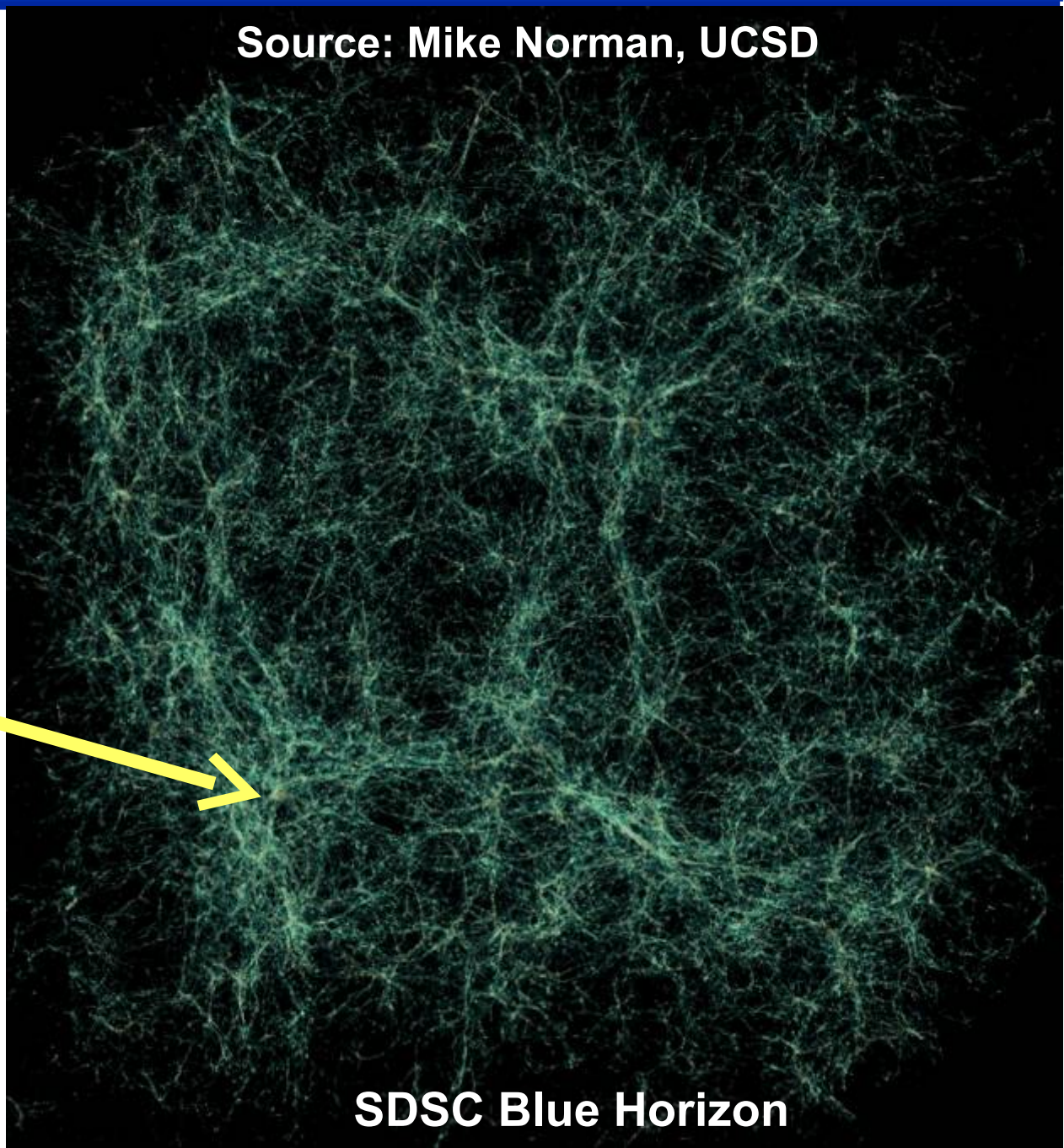
| Year | Production | Experimental | Remarks |
|---|---|---|---|
| 2001 | 0.155 | 0.622-2.5 | SONET/SDH |
| 2002 | 0.622 | 2.5 | SONET/SDH<br>DWDM; GigE Integ. |
| 2003 | 2.5 | 10 | DWDM; 1 + 10 GigE<br>Integration |
| 2005-6 | 10-20 | 2-4 X 10 | λ Switch;<br>λ Provisioning |
| 2007-8 | 30-40 | ~100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

Source: Harvey Newman, Caltech

UCSD
UCIrvine

# Supercomputing as Data Generator: Cosmic Simulator with a Billion Zone and Gigaparticle Resolution

Problem with Uniform Grid-- Gravitation Causes Continuous Increase in Density Until There is a Large Mass in a Single Grid Zone




UCSD
UCIrvine

# Automatic Mesh Refinement (AMR) Allows Digital Exploration of Early Galaxy and Cluster Core Formation

- Background Image Shows Grid Hierarchy Used
  - Key to Resolving Physics is More Sophisticated Software
  - Evolution is from 10Myr to Present Epoch
- Every Galaxy > $10^{11}$ $M_{solar}$ in 100 Mpc/H Volume Adaptively Refined With AMR
  - $256^3$ Base Grid
    - Over 32,000 Grids At 7 Levels Of Refinement
    - Spatial Resolution of 4 kpc at Finest
    - 150,000 CPU-hr On 128-Node IBM SP

Source: Mike Norman, UCSD

# The Cosmic Simulator Needs a 10 Gpbs Dedicated Link to End User

- **$1024^3$ Unigrid or $512^3$ AMR Now Feasible**
  - 8-64 Times The Mass Resolution
  - Can Simulate First Galaxies
  - One Million CPU-Hr Allocation at LLNL
  - Bottleneck--Network Throughput from LLNL to UCSD
- **One Giga-Zone Uniform Grid or $512^3$ AMR Run:**
  - Generates ~10 TeraByte of Output
  - A "Snapshot" is 100s of GB
  - Need to Visually Analyze as We Create SpaceTimes
- **Can Run Evolutions Faster than We Can Archive Them**
  - File Transport Over Shared Internet ~50 Mbit/s
    - 4 Hours to Move ONE Snapshot!
  - A 10 Gbps Dedicated Link Moves One Snapshot per Minute

UCSD UCIrvine

Source: Mike Norman, UCSD

it²

# 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.**

UCSD
UCIrvine

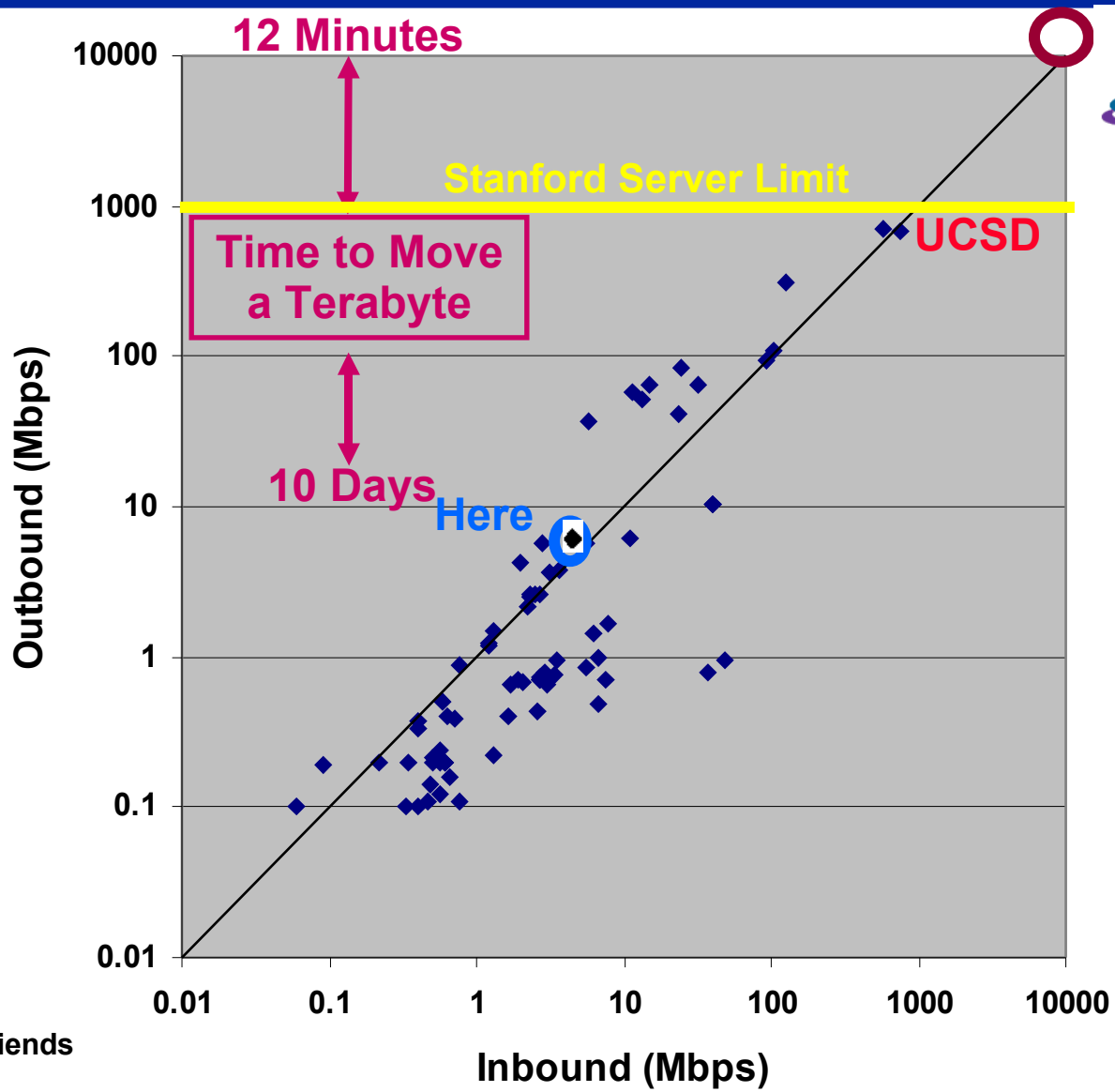
**Source: Jerry Sobieski MAX / University of Maryland**

it²

# Shared Internet Bandwidth: Unpredictable, Widely Varying, Jitter, Asymmetric

**Computers In:**

Australia
Canada
Czech Rep.
India
Japan
Korea
Mexico
Moorea
Netherlands
Poland
Taiwan
United States




OptIPuter

**1000x Normal Internet!**

**Data Intensive Sciences Require Fast Predictable Bandwidth**

Source: Larry Smarr and Friends

**Measured Bandwidth from User Computer to Stanford Gigabit Server in Megabits/sec**
**http://netspeed.stanford.edu/**

UCSD
UCIrvine

it2

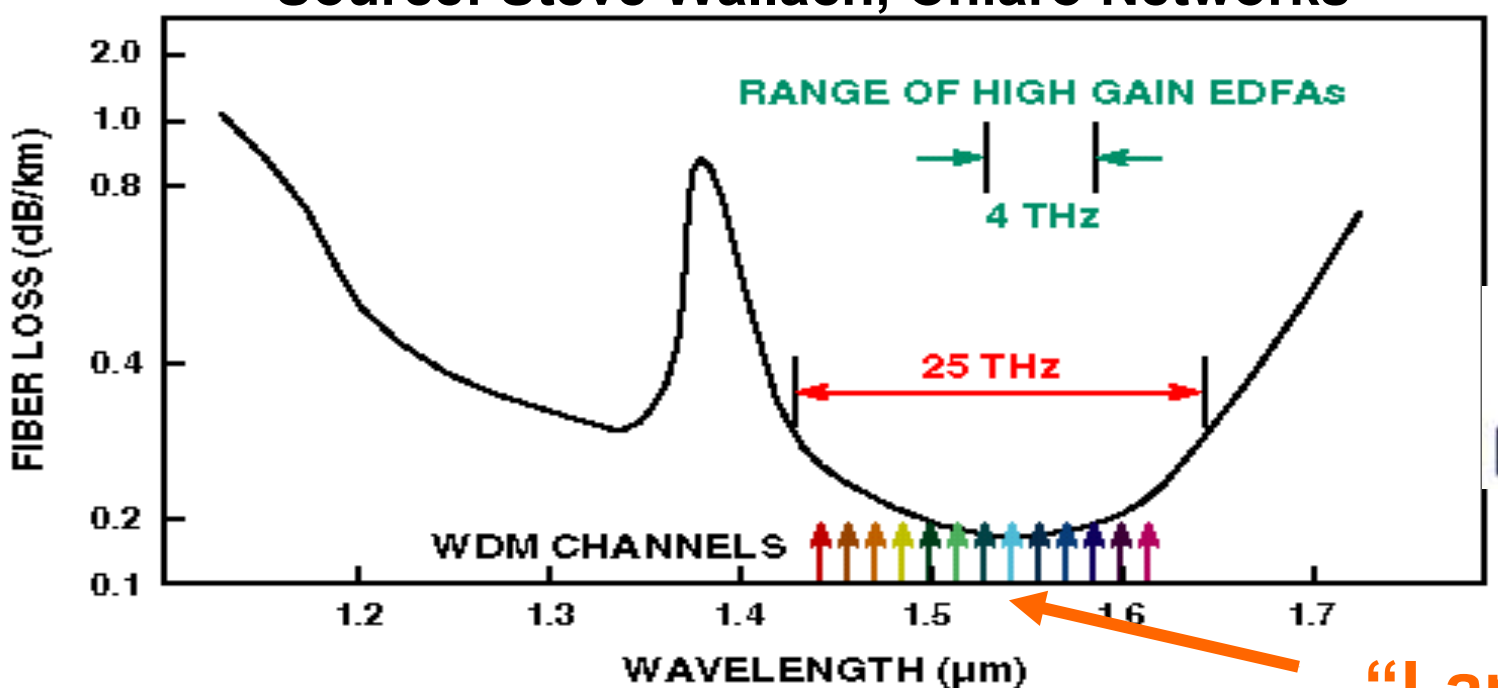
# Dedicated Optical Channels Makes High Performance Cyberinfrastructure Possible

## 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

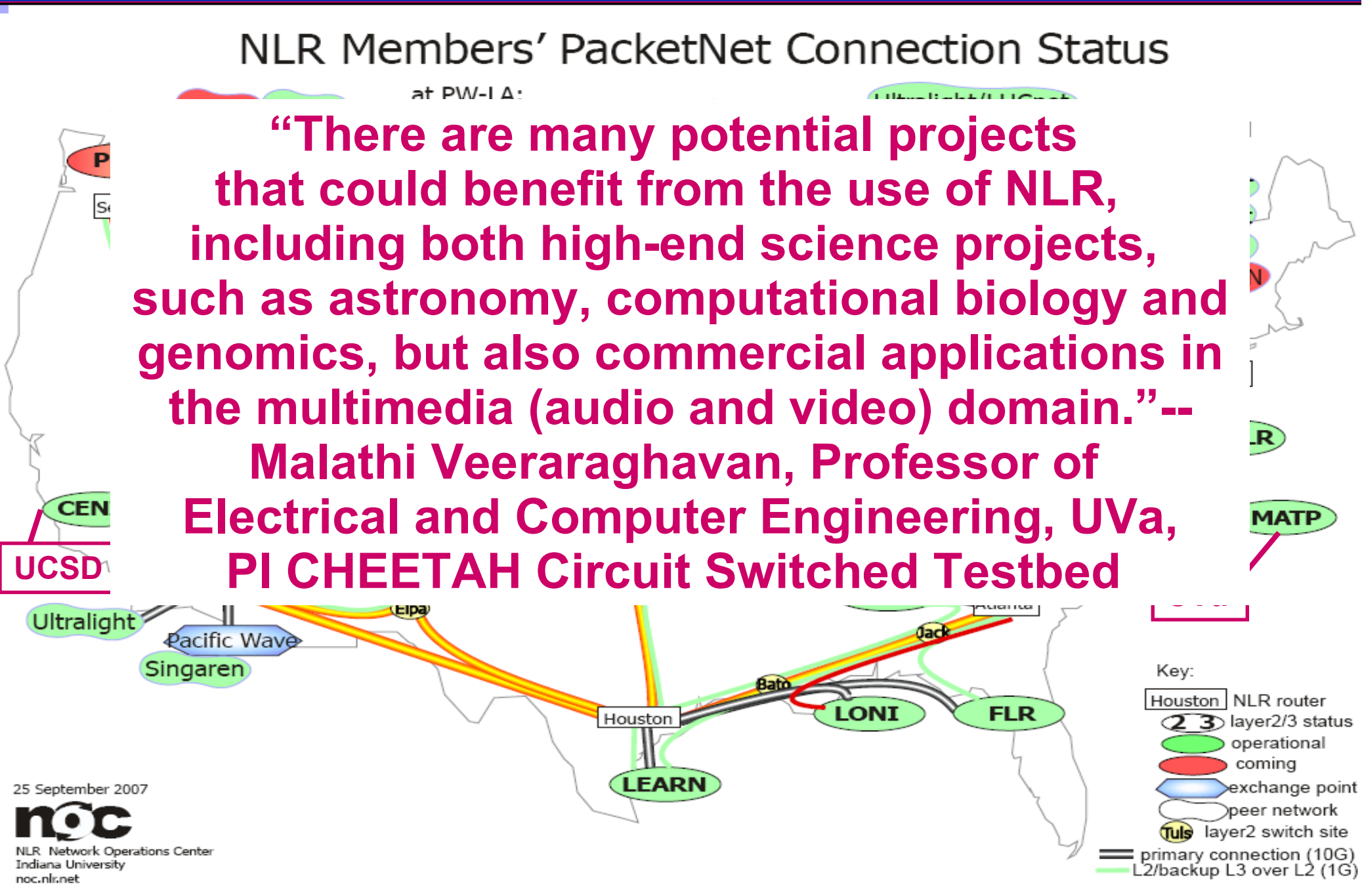
**"Lambdas"**

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

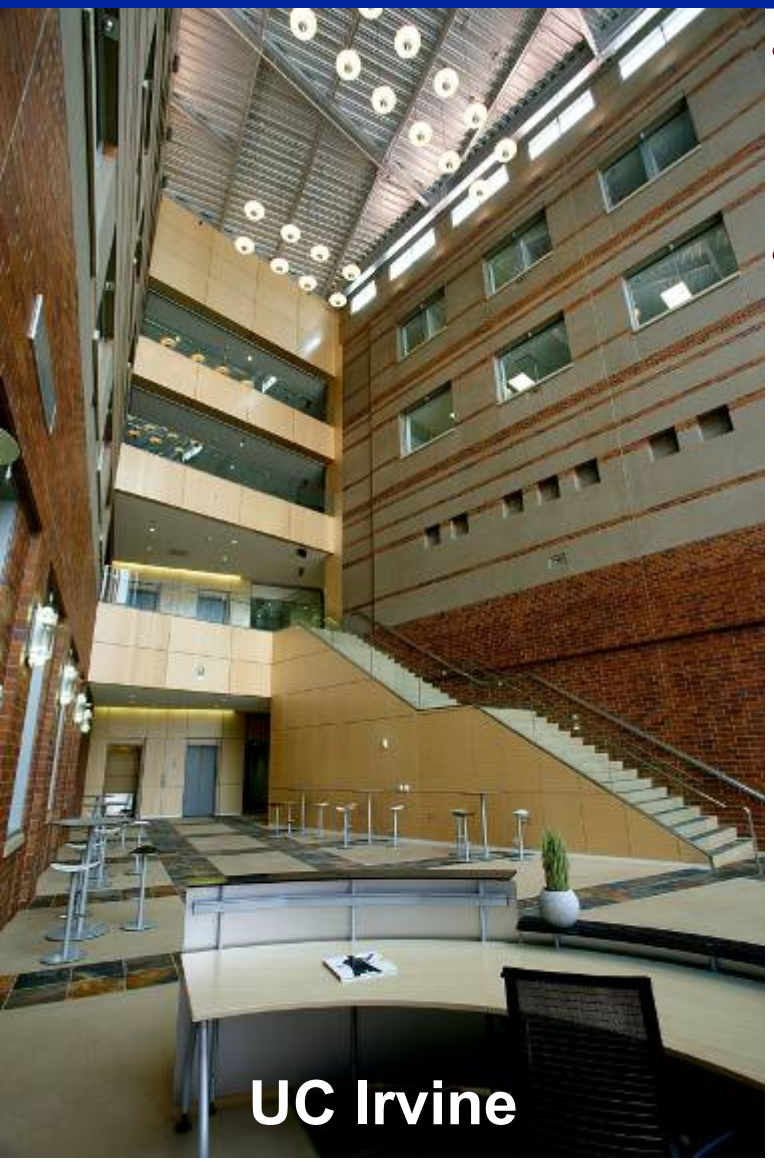
UCSD
UCIrvine

it2

# National LambdaRail
# Serves the University of Virginia



# 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



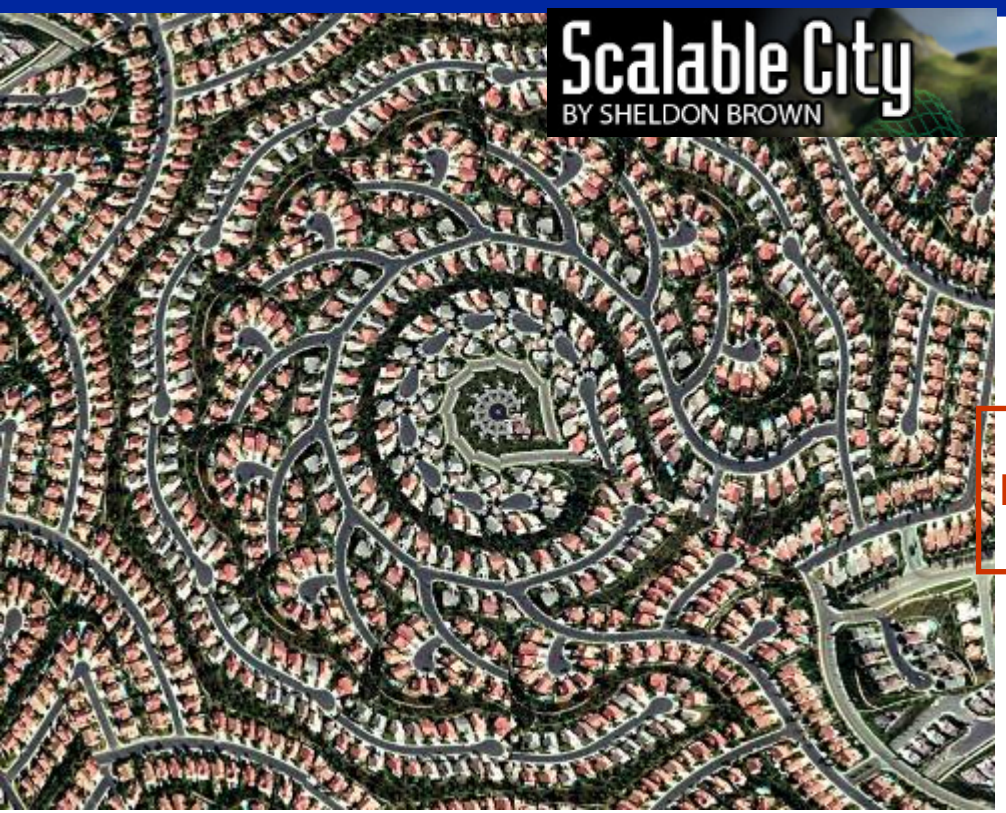
www.calit2.net

Preparing for a World in Which Distance is Eliminated…

UCSD
UCIrvine

it2

# Calit2 Has Facilitated Deep Interactions With the Digital Arts on Both Campuses




Bill Tomlinson, Lynn Carpenter UCI "EcoRaft"



Eric Baumer, UCI

"Researchers Look to Create a Synthesis of Art and Science for the 21st Century"

By John Markoff
NYTimes November 5, 2005

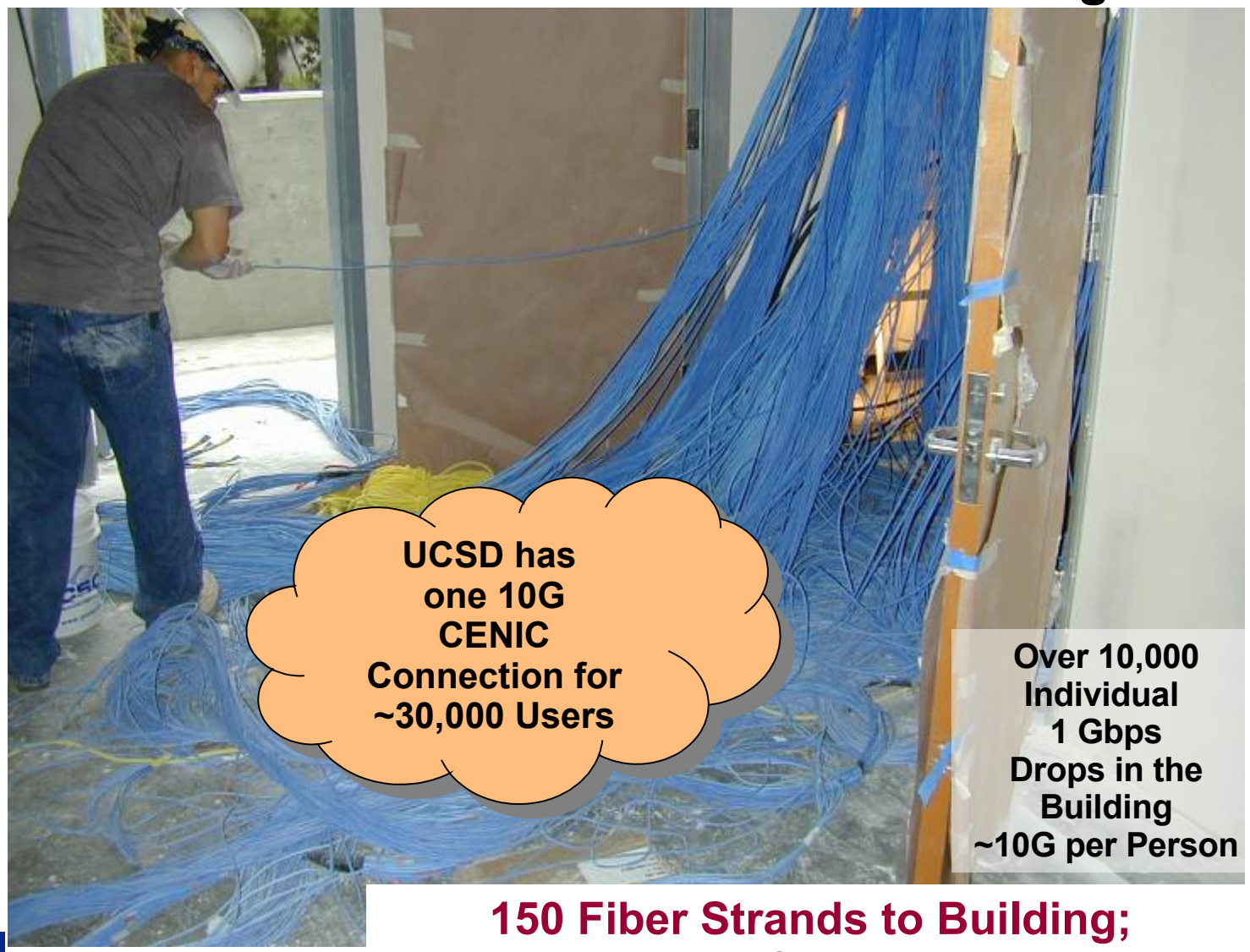
Alex Dragulescu, CRCA

SPECFLIC 1.0 – A Speculative Distributed Social Cinema by Adrienne Jenik



# 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**

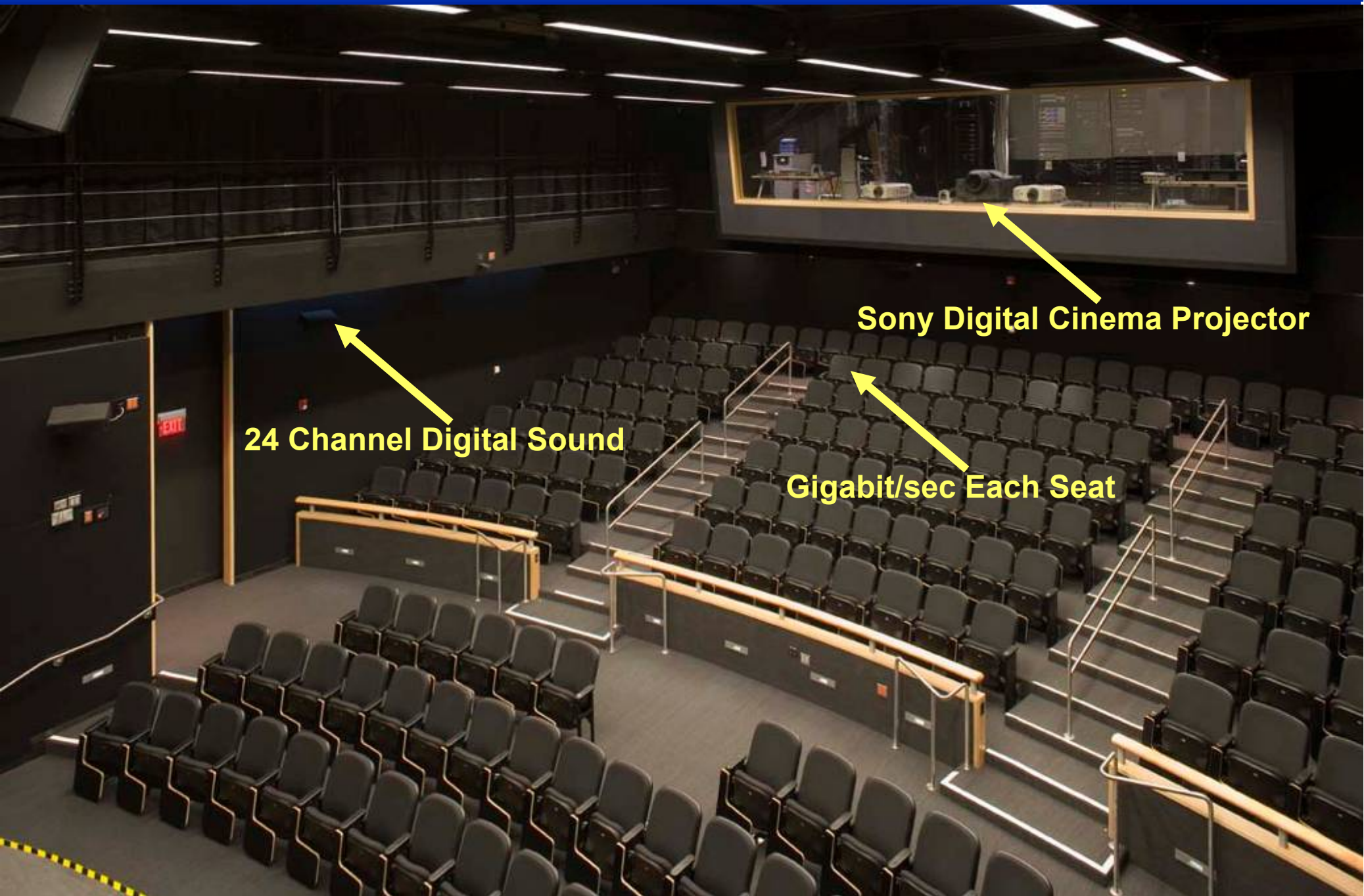
**150 Fiber Strands to Building; Experimental Roof Radio Antenna Farm Ubiquitous WiFi**

Photo: Tim Beach, Calit2

UCSD
UCIrvine

it²

# Building a Global Collaboratorium



# Borderless Collaboration Between Global University Research Centers at 10Gbps

Maxine Brown, Tom DeFanti, Co-Chairs

# iGrid 2005

THE GLOBAL LAMBDA INTEGRATED FACILITY

www.igrid2005.org

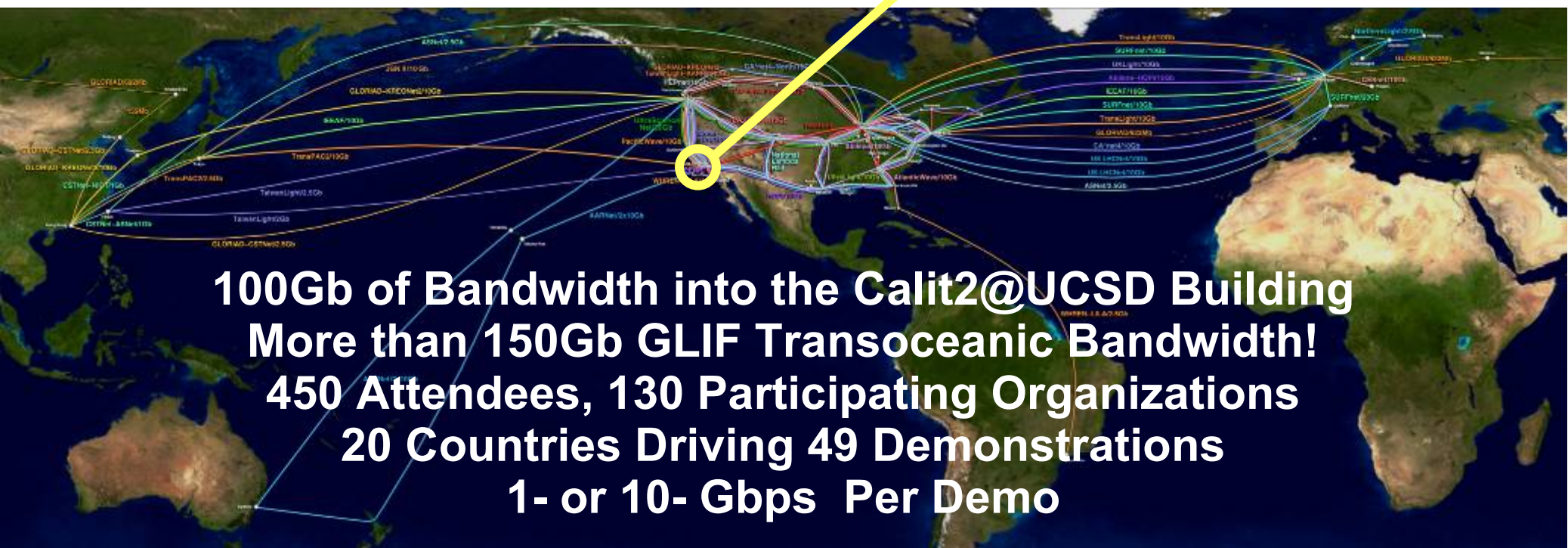


the UC Discovery Grant

**September 26-30, 2005**

**Calit2 @ University of California, San Diego**

**California Institute for Telecommunications and Information Technology**



**100Gb of Bandwidth into the Calit2@UCSD Building**

**More than 150Gb GLIF Transoceanic Bandwidth!**

**450 Attendees, 130 Participating Organizations**

**20 Countries Driving 49 Demonstrations**

**1- or 10- Gbps Per Demo**

# First Trans-Pacific Super High Definition Telepresence Meeting Using Digital Cinema 4k Streams




CineGrid™

Lays Technical Basis for Global Digital Cinema

Sony
NTT
SGI

iGrid2005

it²

# CineGrid @ iGrid2005:
# Six Hours of 4K Projected in Calit2 Auditorium

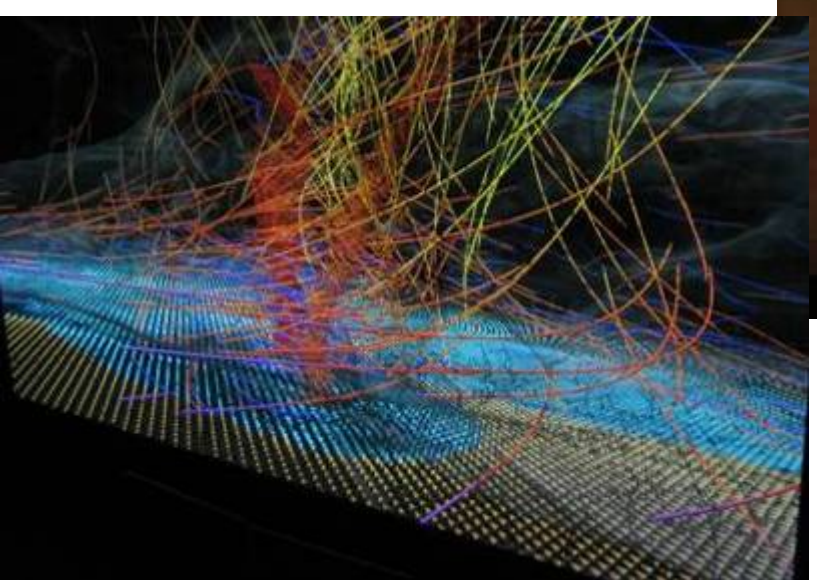
4K Distance Learning





4K Virtual Reality

4K Scientific Visualization





4K Digital Cinema

4K *Anime*



**Source: Laurin Herr**

# 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!**

SDSS

Sloan Digital Sky Survey




UCSD
UCIrvine

www.sdss.org

it²

# 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**

UCSD
UCIrvine

**Source: Jerry Sobieski, DRAGON**

it2

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

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





telescience project



HDTV

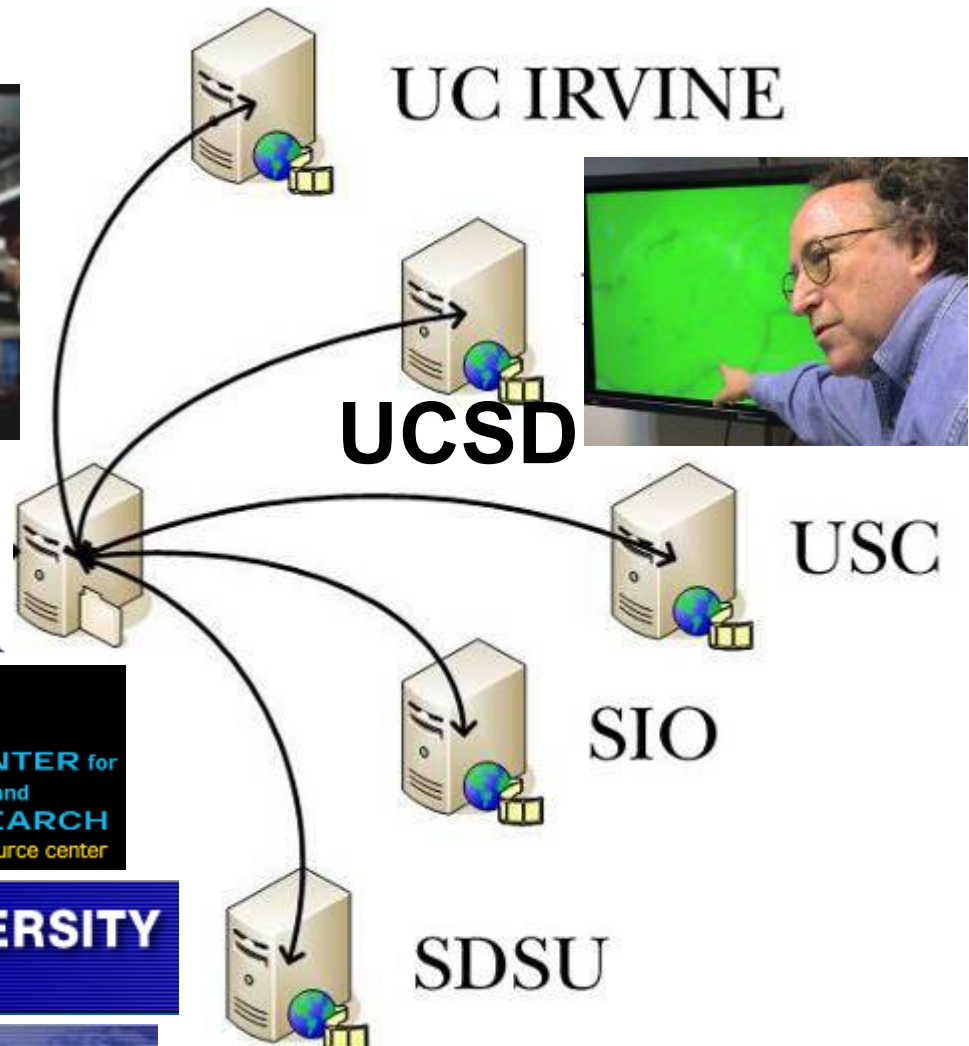
NBCR

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

OSAKA UNIVERSITY

KDDI Labs USA

**Southern California OptIPuter**






Source: Mark Ellisman, UCSD

it²

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



UCSD
UCIrvine

Source John Delaney & Deborah Kelley, UWash

it²

# Gigabit Fibers on the Ocean Floor -- Controlling Sensors and HDTV Cameras Remotely




**LOOKING is Driven By NEPTUNE CI Requirements**

**LOOKING:**
**(Laboratory for the Ocean Observatory Knowledge Integration Grid)**

**http://lookingtosea.ucsd.edu/**

- **Goal:**
  - **Prototype Cyberinfrastructure for NSF's Ocean Research Interactive Observatory Networks (ORION) Building on OptIPuter**
- **LOOKING NSF ITR with PIs:**
  - **John Orcutt & Larry Smarr - UCSD**
  - **John Delaney & Ed Lazowska –UW**
  - **Mark Abbott – OSU**
- **Collaborators at:**
  - **MBARI, WHOI, NCSA, UIC, CalPoly, UVic, CANARIE, Microsoft, NEPTUNE-Canarie**

UCSD UCIrvine

NSF

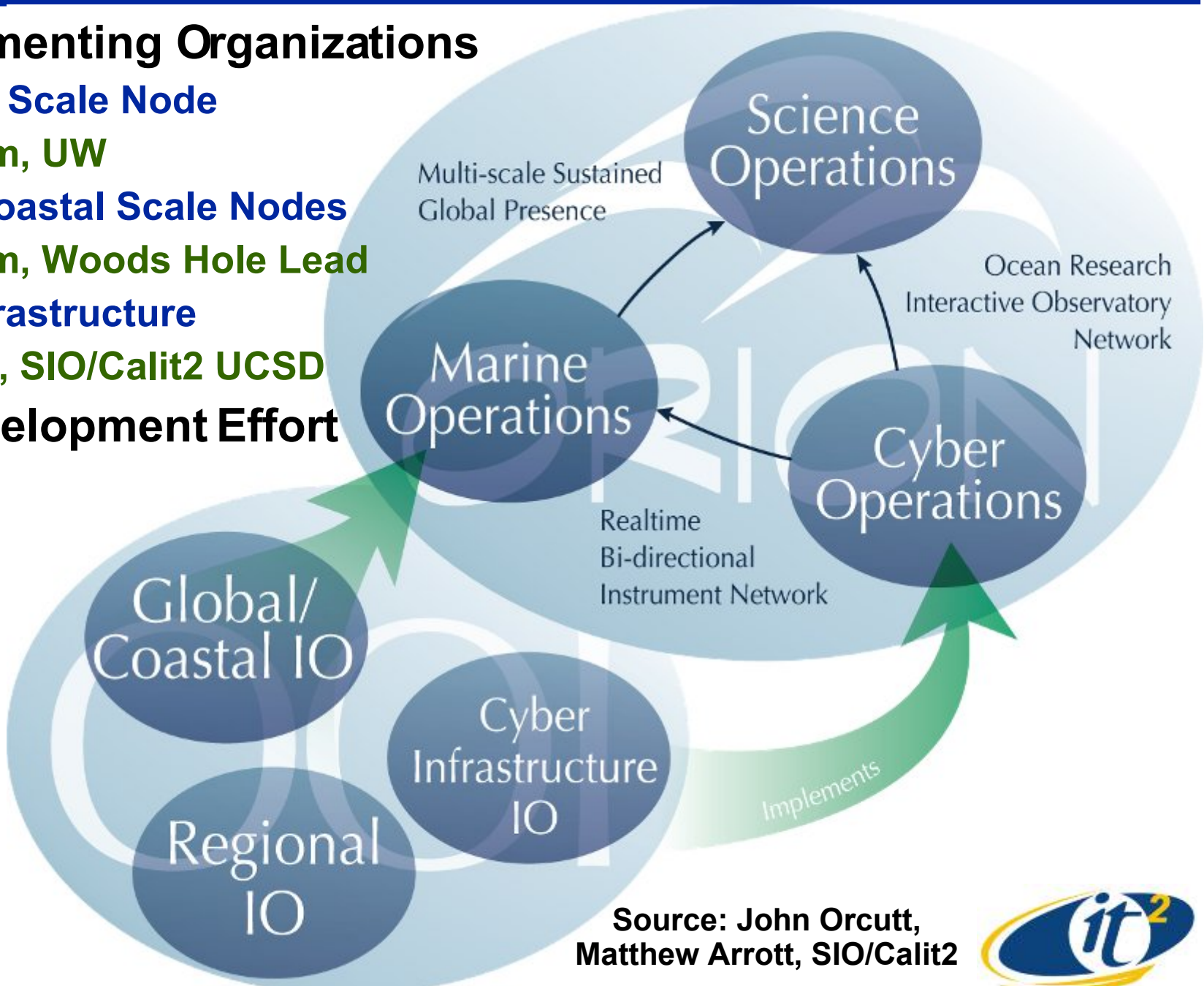
ocean research interactive ORION observatory networks

**Making Management of Gigabit Flows Routine**

it²

# Ocean Observatory Initiative -- Initial Stages

- **OOI Implementing Organizations**
  - **Regional Scale Node**
    - **$150m, UW**
  - **Global/Coastal Scale Nodes**
    - **$120m, Woods Hole Lead**
  - **Cyberinfrastructure**
    - **$30m, SIO/Calit2 UCSD**
- **6 Year Development Effort**



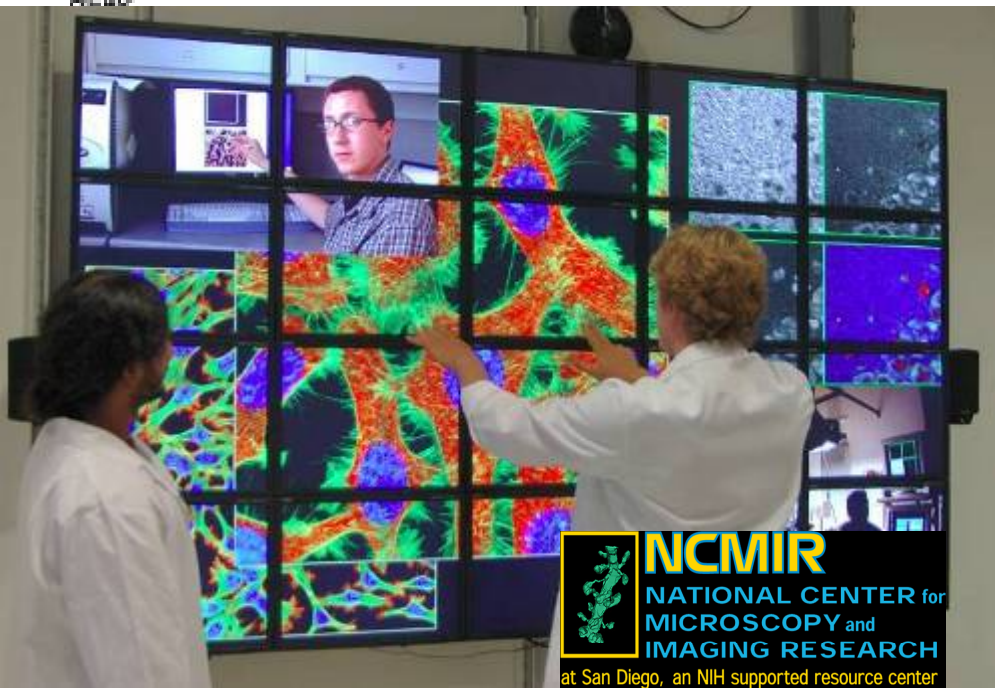

Source: John Orcutt, Matthew Arrott, SIO/Calit2

UCSD UCIrvine

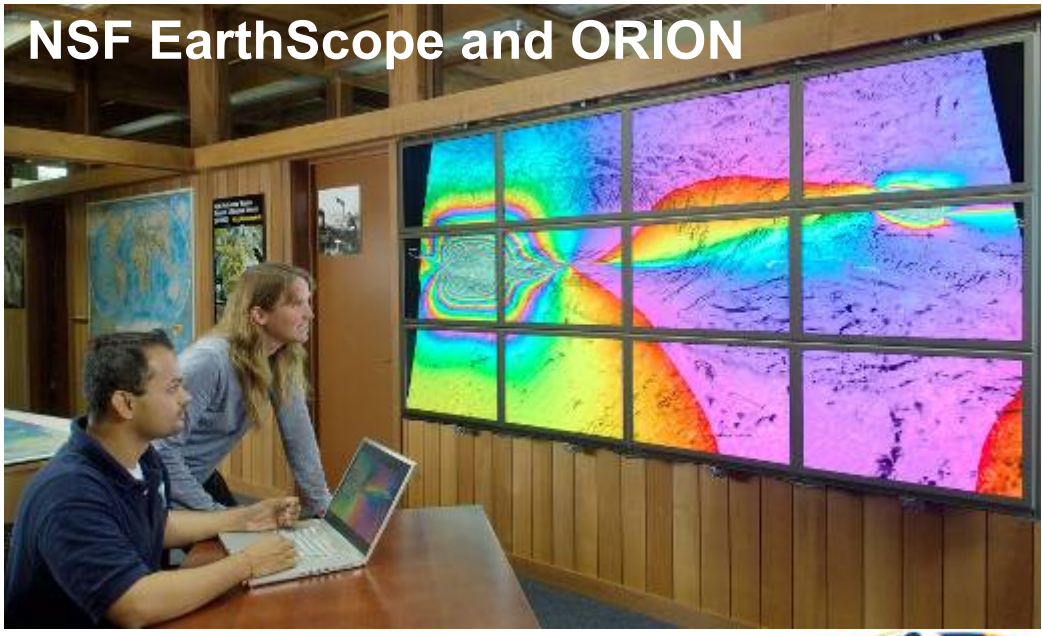
# The OptIPuter Project – Creating High Resolution Portals Over Dedicated Optical Channels to Global Science Data

- **NSF Large Information Technology Research Proposal**
  - Calit2 (UCSD, UCI) and UIC Lead Campuses—Larry Smarr PI
  - Partnering Campuses: SDSC, USC, SDSU, NCSA, NW, TA&M, UvA, SARA, NASA Goddard, KISTI, AIST, CRC(Canada), CICESE (Mexico)
- **Engaged Industrial Partners:**
  - IBM, Sun, Telcordia, Chiaro, Calient, Glimmerglass, Lucent
- **$13.5 Million Over Five Years—Now In the Six and Final Yea..**

NIH Biomedical Informatics Research Network

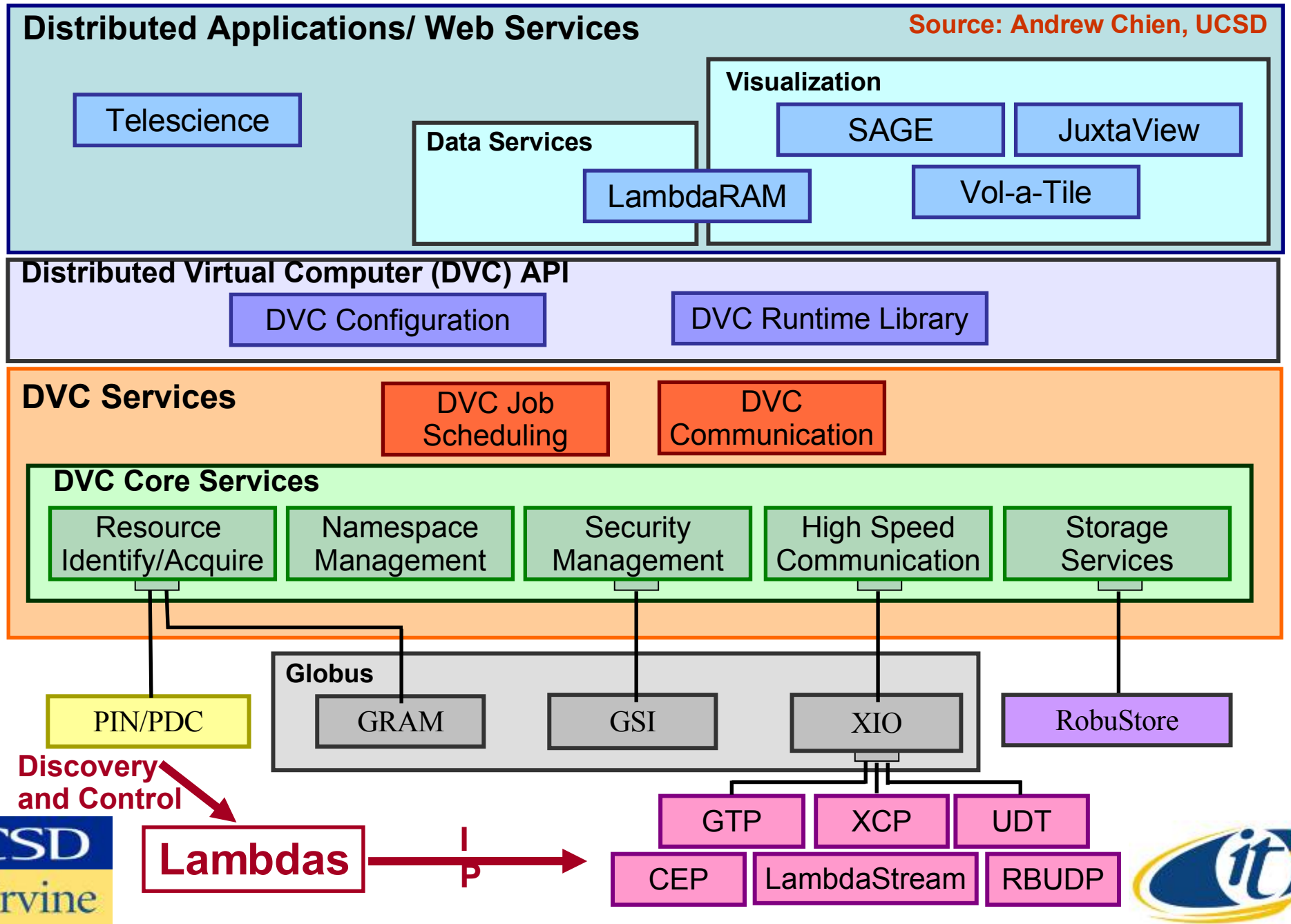



NSF EarthScope and ORION



SCRIPPS INSTITUTION OF OCEANOGRAPHY

# OptIPuter Software Architecture--a Service-Oriented Architecture Integrating Lambdas Into the Grid

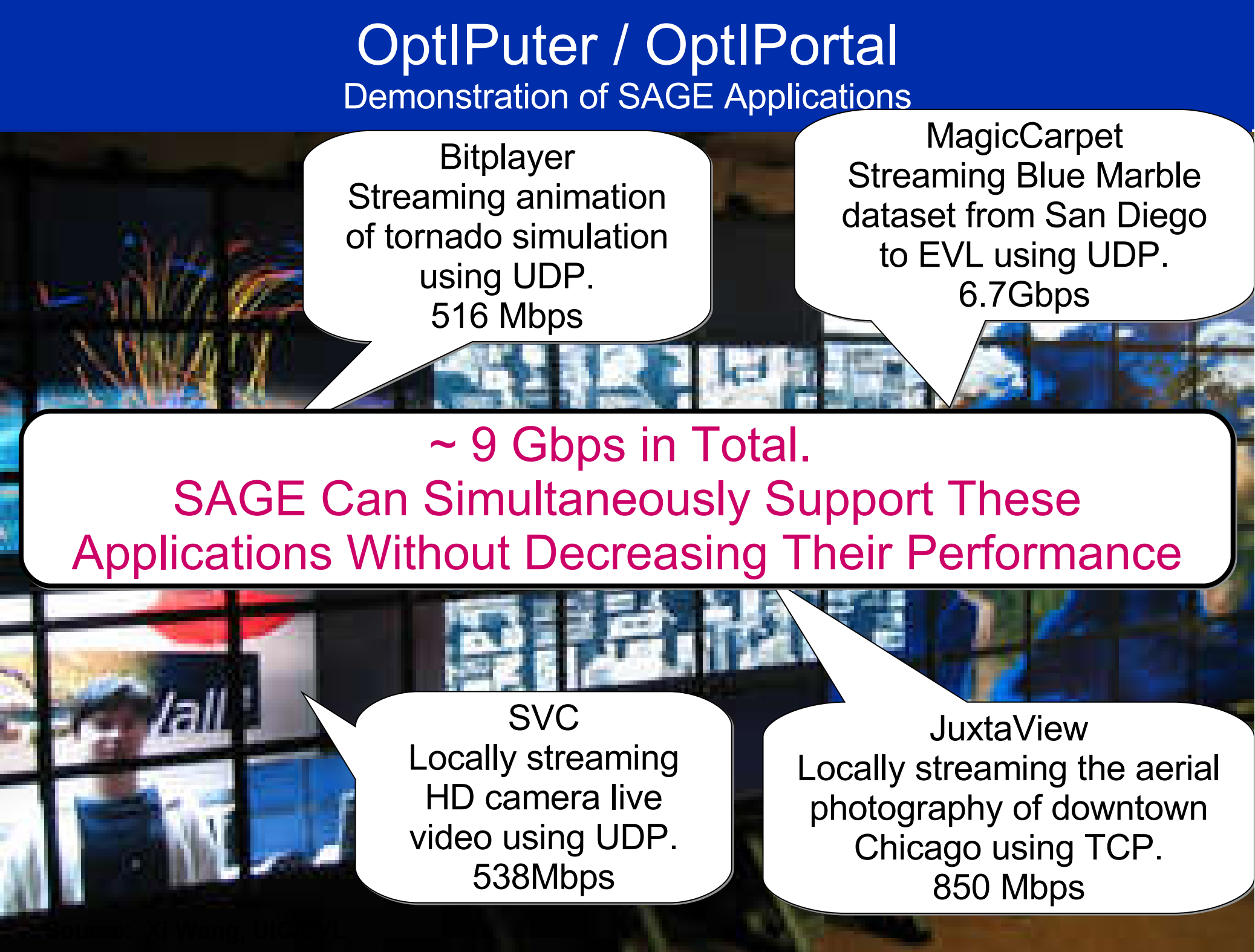



UCSD UCIrvine

it2

# OptIPuter / OptIPortal

## Demonstration of SAGE Applications



# 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





UCSD UCIrvine

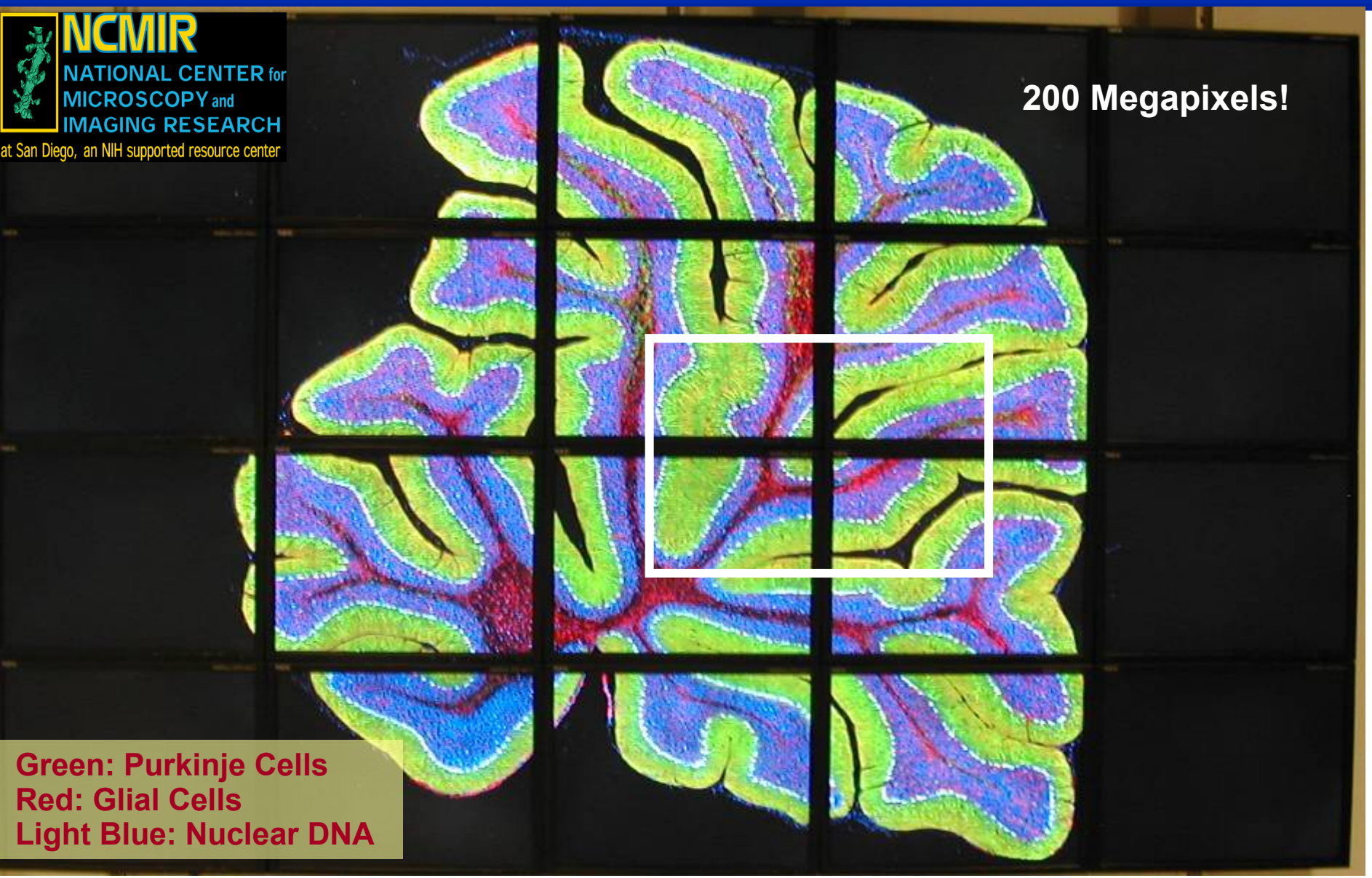
Powered by Rocks ROCKS

Source: Phil Papadopoulos SDSC, Calit2

it²

# OptIPuter Scalable Displays Are Used for Multi-Scale Biomedical Imaging

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



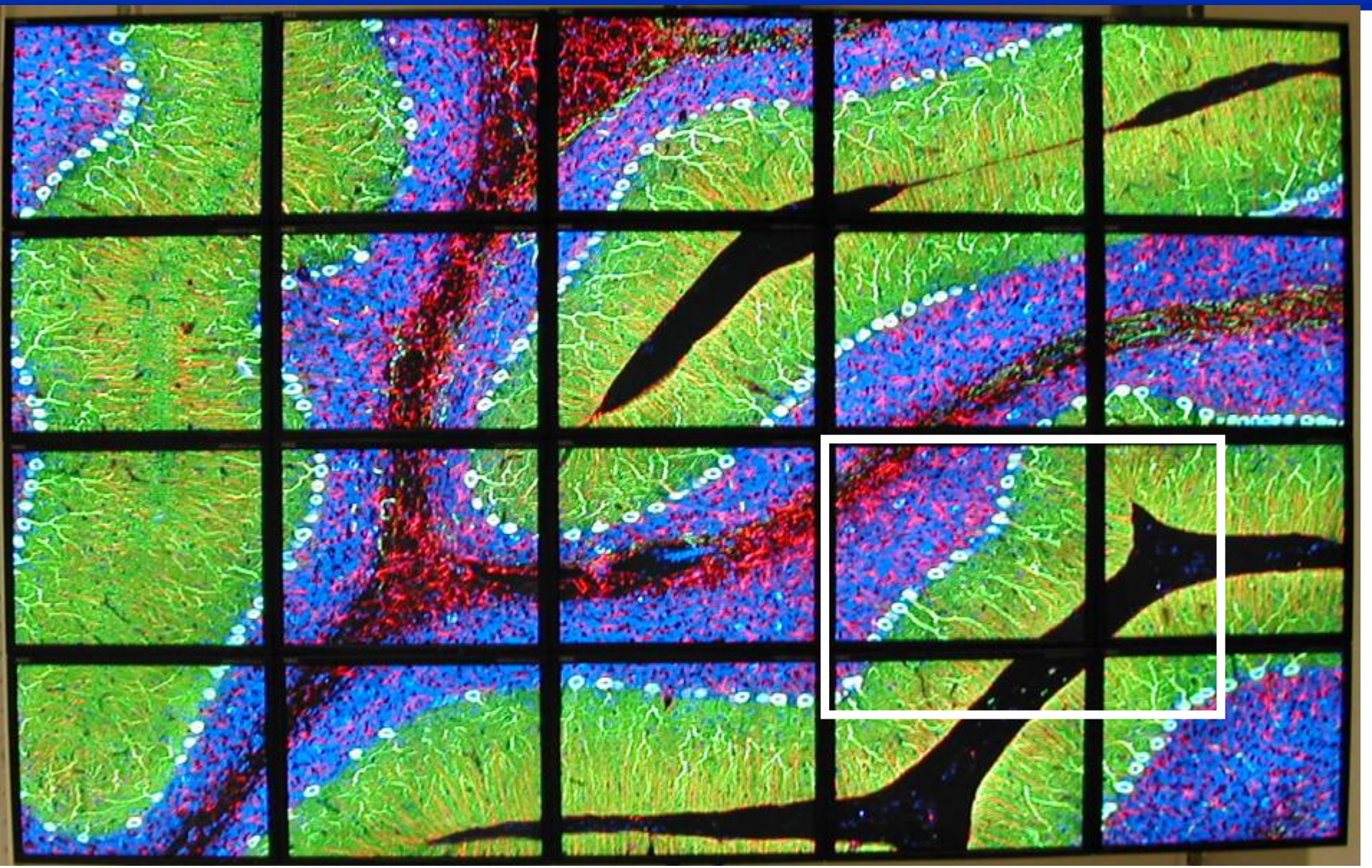

Source: Mark Ellisman, David Lee, Jason Leigh

UCSD
UCIrvine

Two-Photon Laser Confocal Microscope Montage of 40x36=1440 Images in 3 Channels of a Mid-Sagittal Section of Rat Cerebellum Acquired Over an 8-hour Period

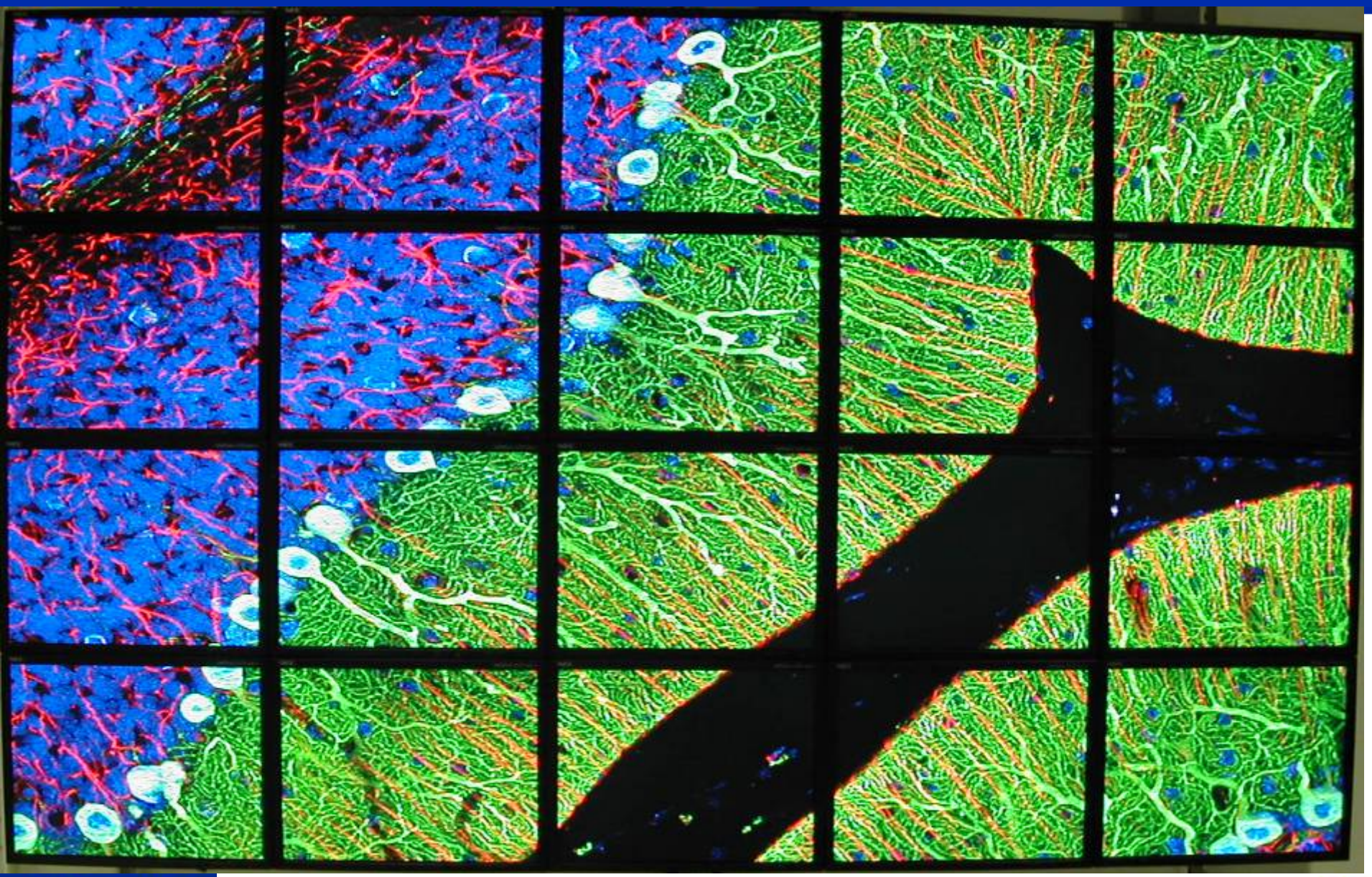
it²

# Scalable Displays Allow Both Global Content and Fine Detail



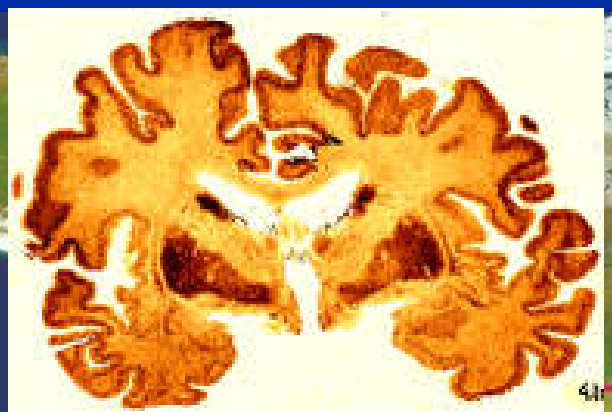
UCSD
UCIrvine

# Allows for Interactive Zooming from Cerebellum to Individual Neurons



UCSD
UCIrvine

# San Diego Interactive Imaging of High Resolution Brain Slices Generated at McGill University



CANARIE



**There are 7407 Slices at 20 µm**
**Each Image has 8513 x 12,472 pixels**

Saskatoon
Winnipeg
McGill
Ottawa
Montreal
Charlottetown
St. John's
Fredericton
Halifax
Toronto
Chicago
New York
Los Angeles
San Diego

cenic
Corporation for Education Network Initiatives in California





NLR
light the future

CA*net4 Network
GLIF Network

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

Source: Mark Ellisman, UCSD, Calit2

UCSD
UCIrvine

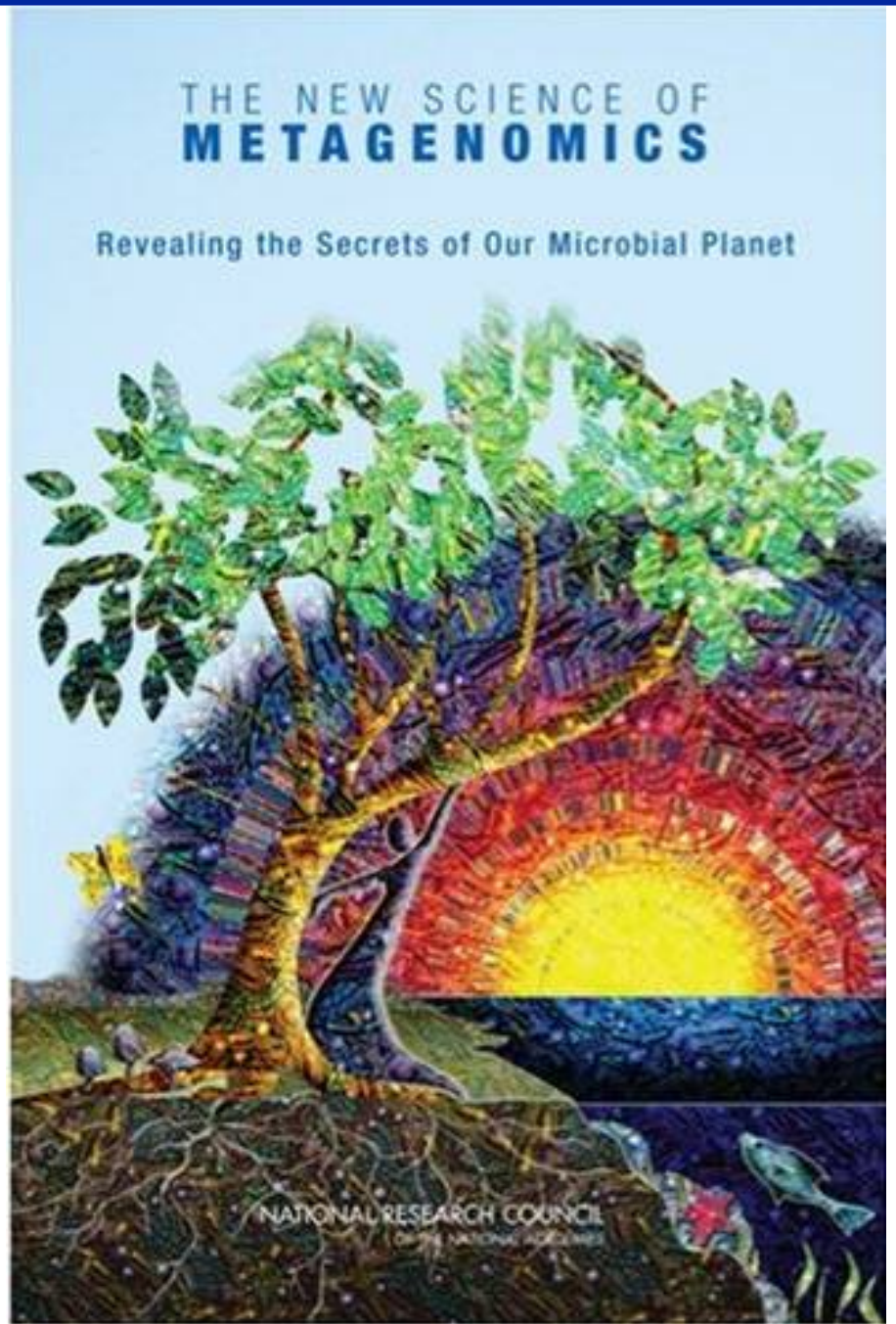
**Canada and California are Setting Up CENIC-CANARIE Collaborations**

it2

# The New Science of Metagenomics

**NRC Report:**

**Metagenomic data should be made publicly available in international archives as rapidly as possible.**




**"The emerging field of metagenomics, where the DNA of entire communities of microbes is studied simultaneously, presents the greatest opportunity -- perhaps since the invention of the microscope – to revolutionize understanding of the microbial world." –**

**National Research Council**
**March 27, 2007**

UCSD
UCIrvine

it²

# 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!**

UCSD
UCIrvine

J. Craig Venter INSTITUTE

it²

# Calit2's Direct Access Core Architecture Will Create Next Generation Metagenomics Server

Gordon and Betty MOORE FOUNDATION

**Sargasso Sea Data**

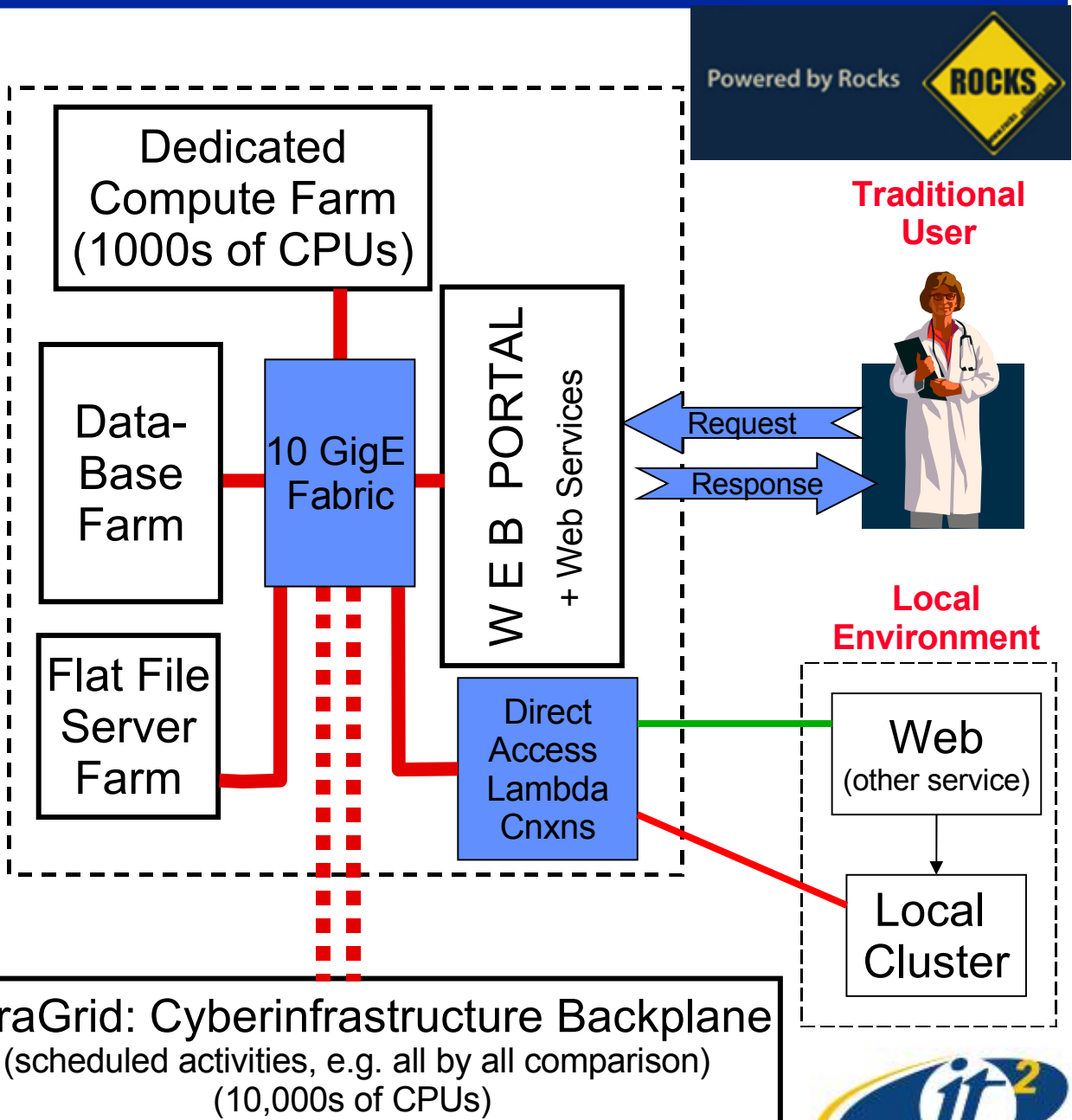
**Sorcerer II Expedition (GOS)**

**JGI Community Sequencing Project**

**Moore Marine Microbial Project**

**NASA and NOAA Satellite Data**

**Community Microbial Metagenomics Data**




**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

it2

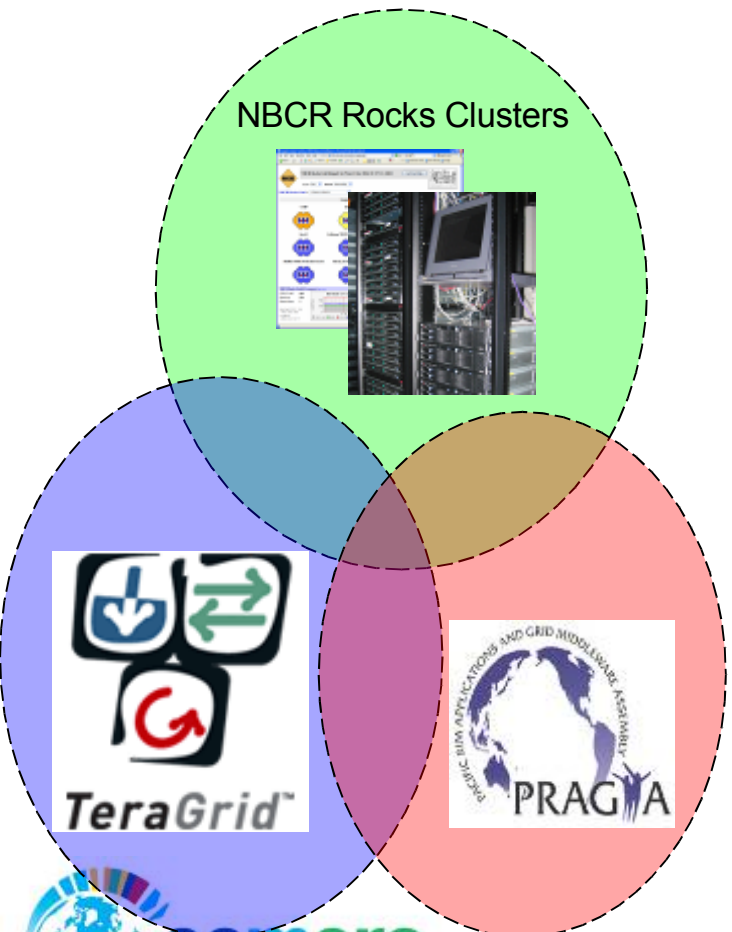
# CAMERA Builds on Cyberinfrastructure Grid, Workflow, and Portal Projects in a Service Oriented Architecture

National Biomedical Computation Resource
*an NIH supported resource center*

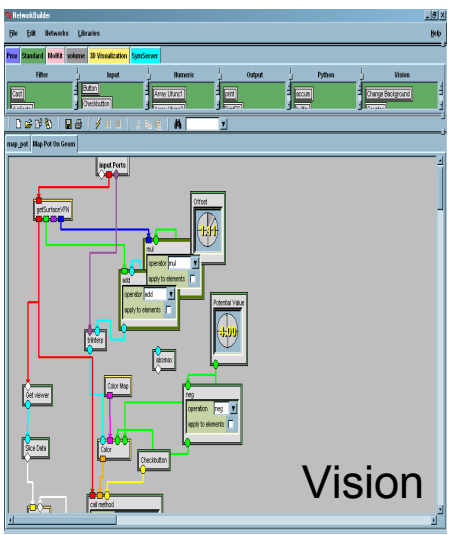
**Located in Calit2@UCSD Building**

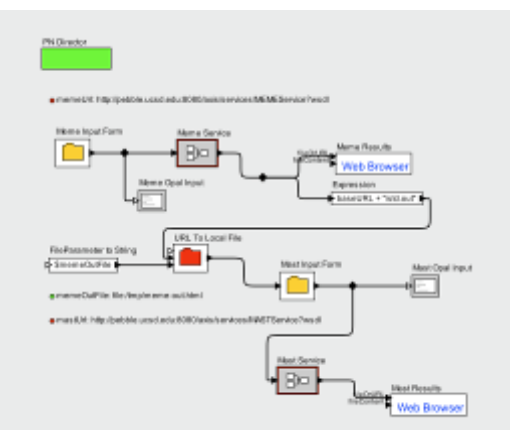
## yberinfrastructure: Raw Resources, Middleware & Execution Environment

### Virtual Organizations



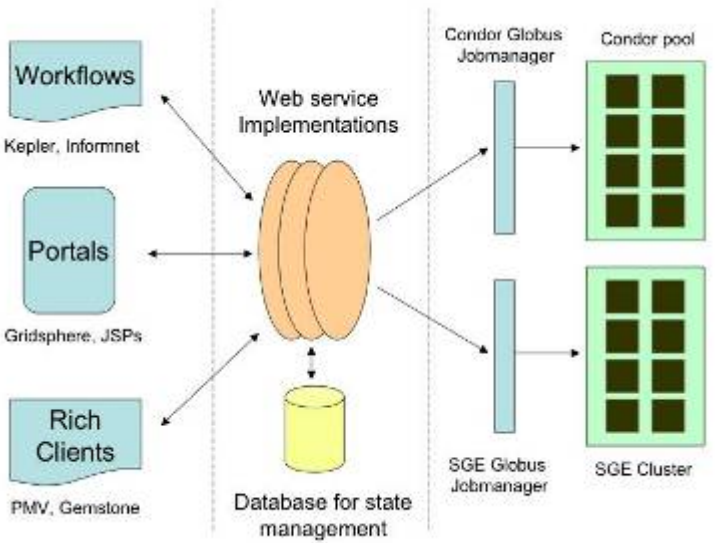

### Workflow Management




KEPLER

### Web Services




### Telescience Portal

telescience project

it²

# “Instant” Global Microbial Metagenomics CyberCommunity

## Over 1300 Registered Users From 48 Countries



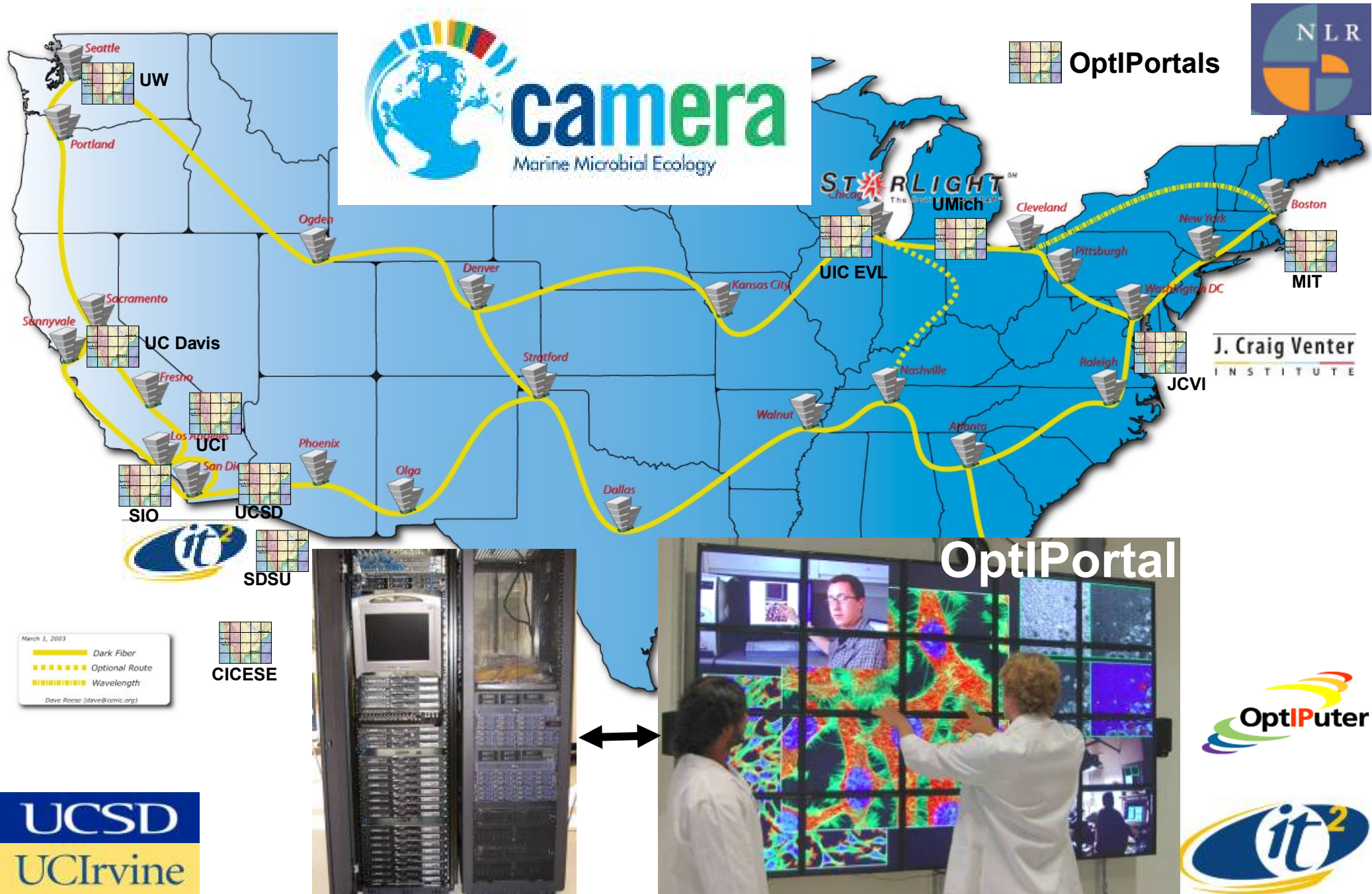

| | |
|---|---|
| USA | 761 |
| United Kingdom | 64 |
| Germany | 54 |
| Canada | 46 |
| France | 44 |
| Brazil | 33 |

camera
Marine Microbial Ecology

J. Craig Venter
INSTITUTE

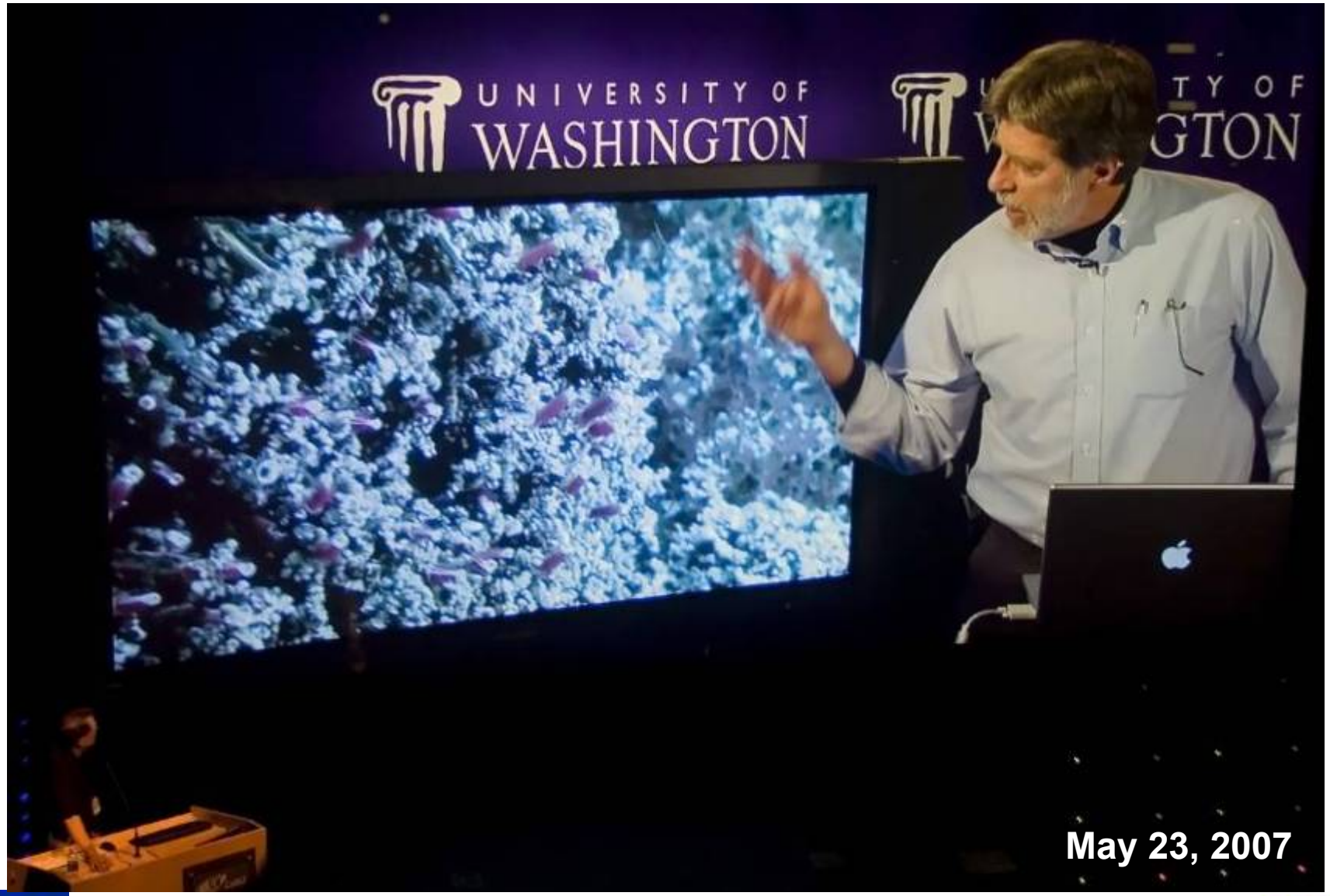
it2

# An Emerging High Performance Collaboratory for Microbial Metagenomics



# e-Science Collaboratory Without Walls Enabled by Uncompressed HD Telepresence

1500 Mbits/sec Calit2 to UW Research Channel Over NLR




John Delaney, PI LOOKING, Neptune

Photo: Harry Ammons, SDSC

UCSD
UCIrvine

# Goal for SC'07
# iHDTV Integrated into OptIPortal

SC07 is the International Conference for High Performance Computing, Networking, Storage and Analysis

**Moving from Compressed HD to Uncompressed iHDTV Reno to UW in Seattle**






**Source: Michael Wellings**
**Research Channel**
**Univ. Washington**

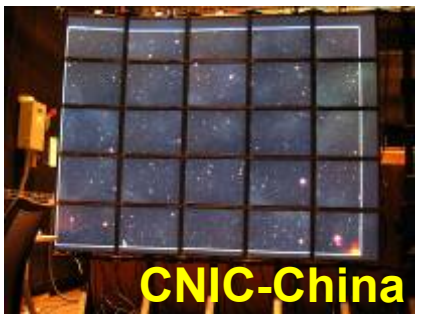
UCSD
UCIrvine

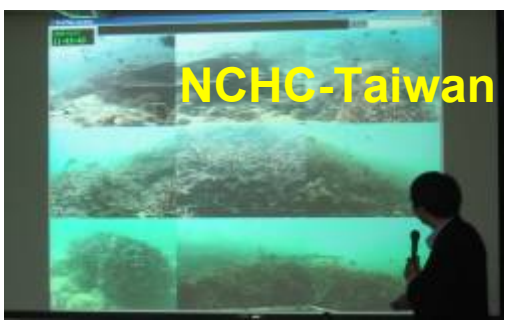
# Rocks / SAGE OptIPortals Are Being Adopted Globally


AIST-Japan


KISTI-Korea


UZurich


CNIC-China


NCHC-Taiwan


Osaka U-Japan

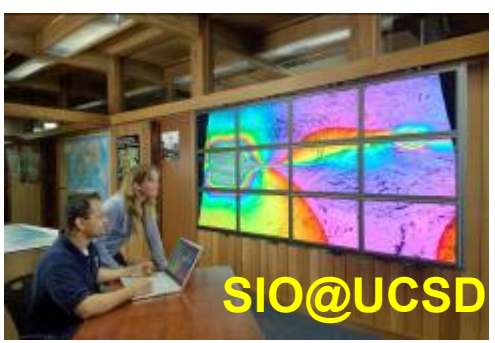

NCSA & TRECC


UIC


Calit2@UCI


Calit2@UCSD


NCMIR@UCSD


SIO@UCSD

UCSD UCIrvine

Powered by Rocks ROCKS

evl electronic visualization laboratory

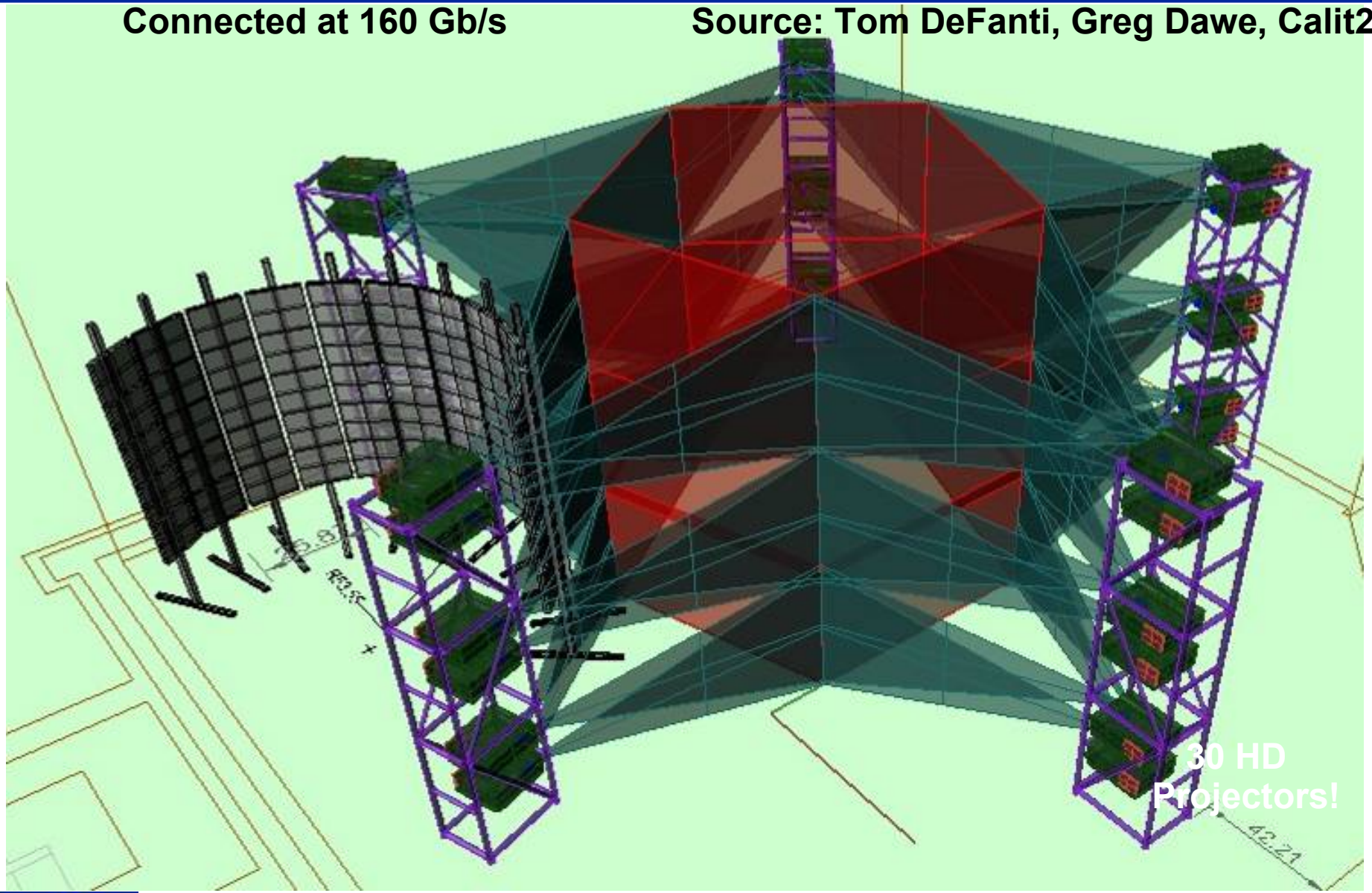
it2

# EVL's SAGE Global Visualcasting to Europe September 2007



# 3D OptIPortals: Calit2 StarCAVE and Varrier Alpha Tests of Telepresence "Holodecks"

**Connected at 160 Gb/s** **Source: Tom DeFanti, Greg Dawe, Calit2**




UCSD
UCIrvine

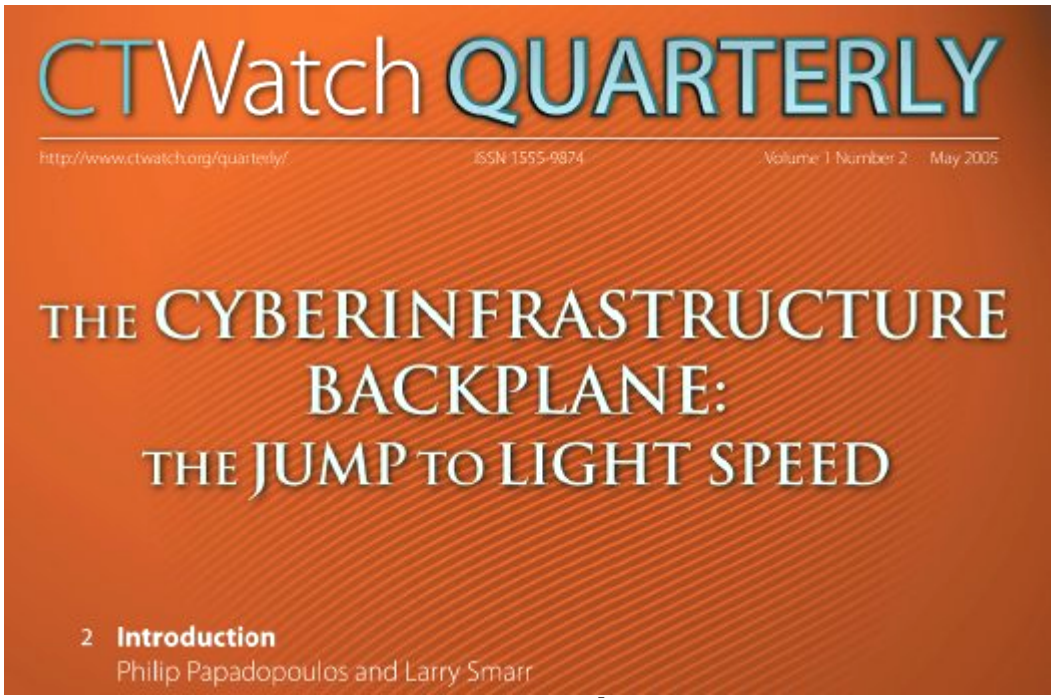
**60 GB Texture Memory,**
**Renders Images 3,200 Times the Speed of Single PC**

it2

# How Do You Get From Your Lab to the National LambdaRail?

**"Research is being stalled by 'information overload,' Mr. Bement said, because data from digital instruments are piling up far faster than researchers can study. In particular, he said, campus networks need to be improved. High-speed data lines crossing the nation are the equivalent of six-lane superhighways, he said. But networks at colleges and universities are not so capable. "Those massive conduits are reduced to two-lane roads at most college and university campuses," he said. Improving cyberinfrastructure, he said, "will transform the capabilities of campus-based scientists."**

**-- Arden Bement, the director of the National Science Foundation**




www.ctwatch.org

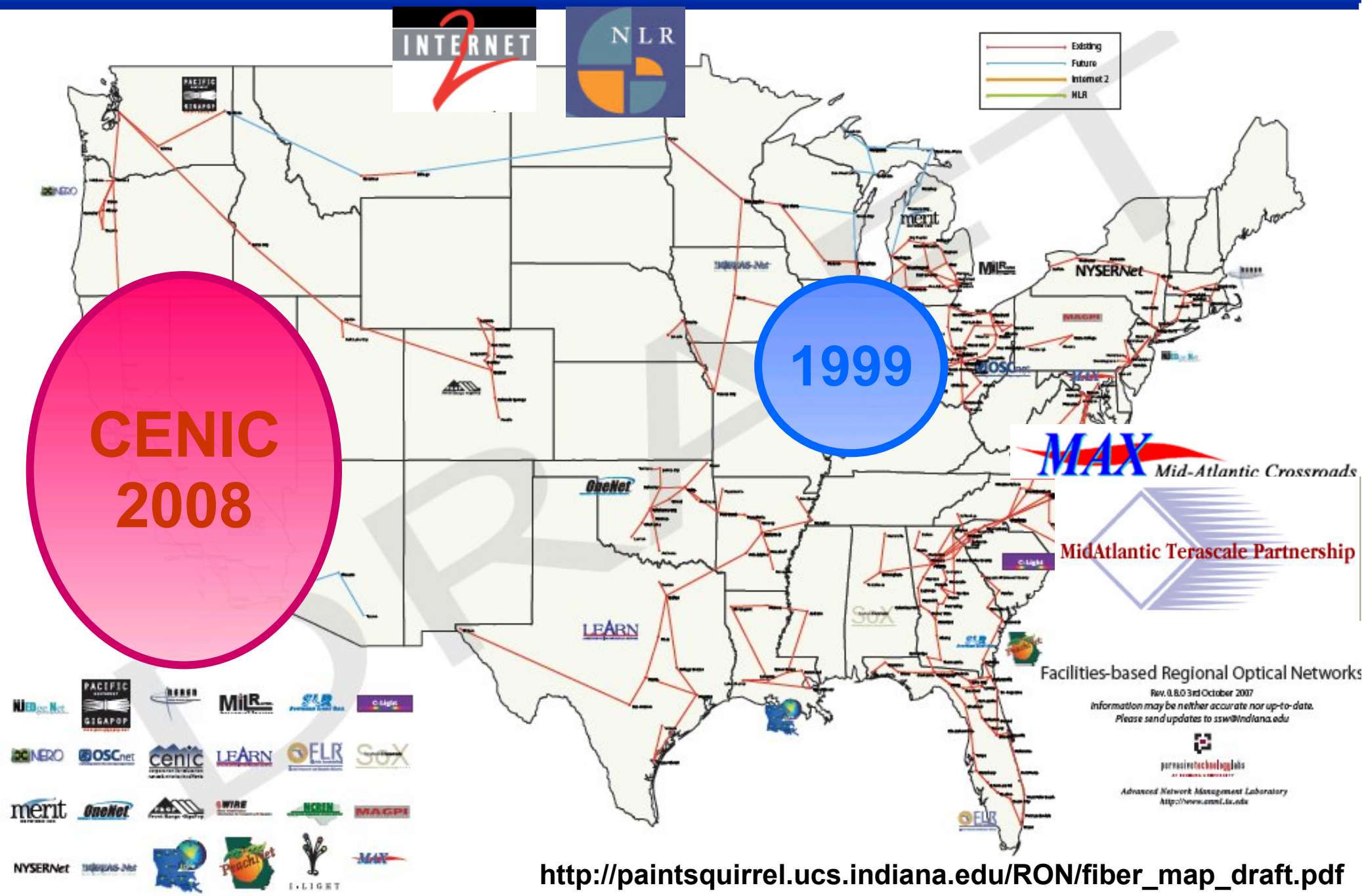
UCSD
UCIrvine

it²

# Detailed Backup Slides on CENIC and UCSD Campus Infrastructure

UCSD
UCIrvine

# Interconnecting Regional Optical Networks Is Driving Campus Optical Infrastructure Deployment



# California (CENIC) Network Directions

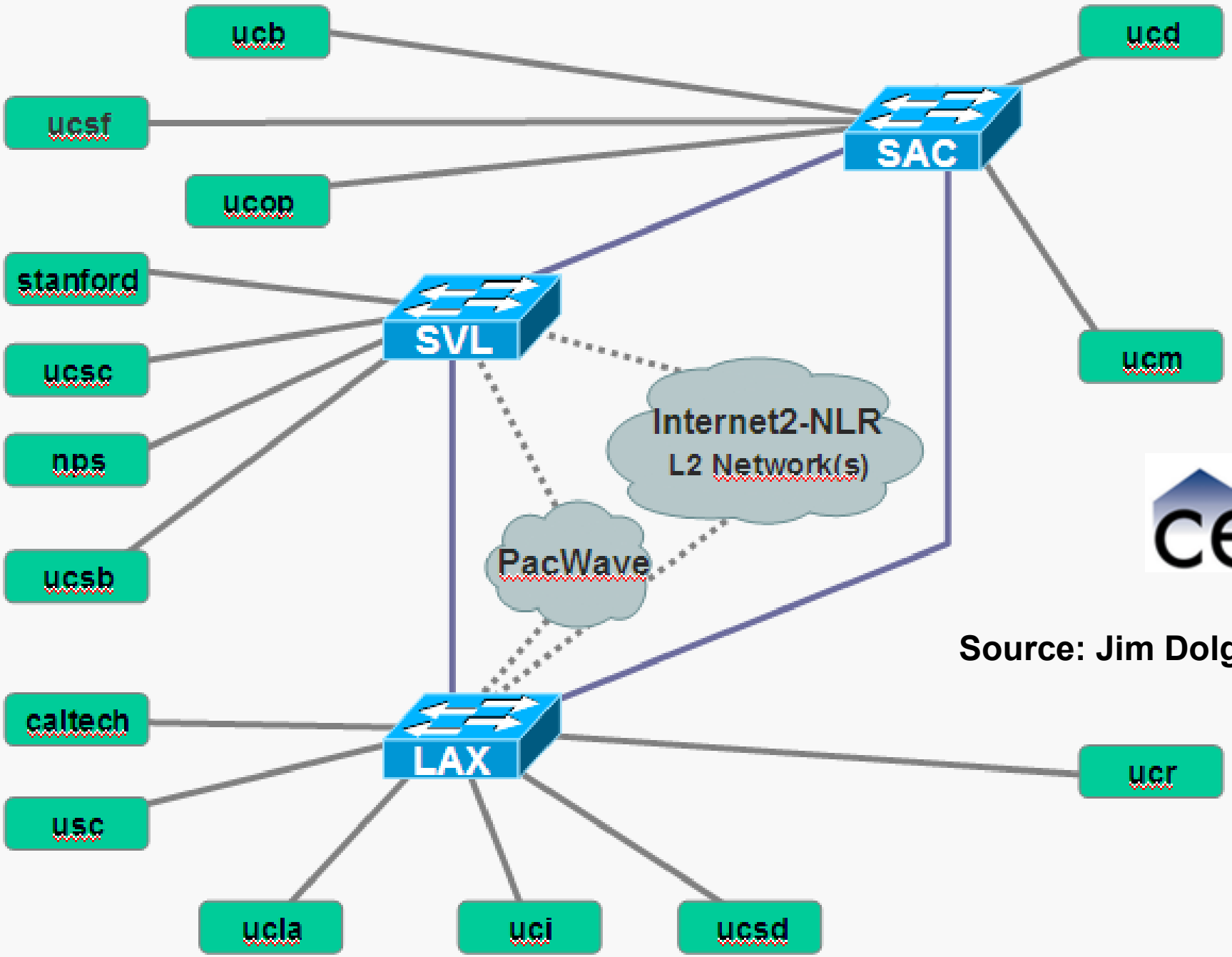
- More Bandwidth to Research University Campuses
  - One or Two 10GE Connections to Every Campus
- More Bandwidth on the Backbone
  - 40Gbps Or 100Gbps
- Support for New Protocols and Features
  - IPv6 Multicast
  - Jumbo Frames: 9000 (or More) Bytes
- "Hybrid Network" Design, Incorporating Traditional Routed IP Service and the New Frame and Optical Circuit Services:
  - "HPRng-L3" = Routed IP Network
  - "HPRng-L2" = Switched Ethernet Network
  - "HPRng-L1" = Switched Optical Network

} CalREN-XD

UCSD UCIrvine

Source: Jim Dolgonas, CENIC

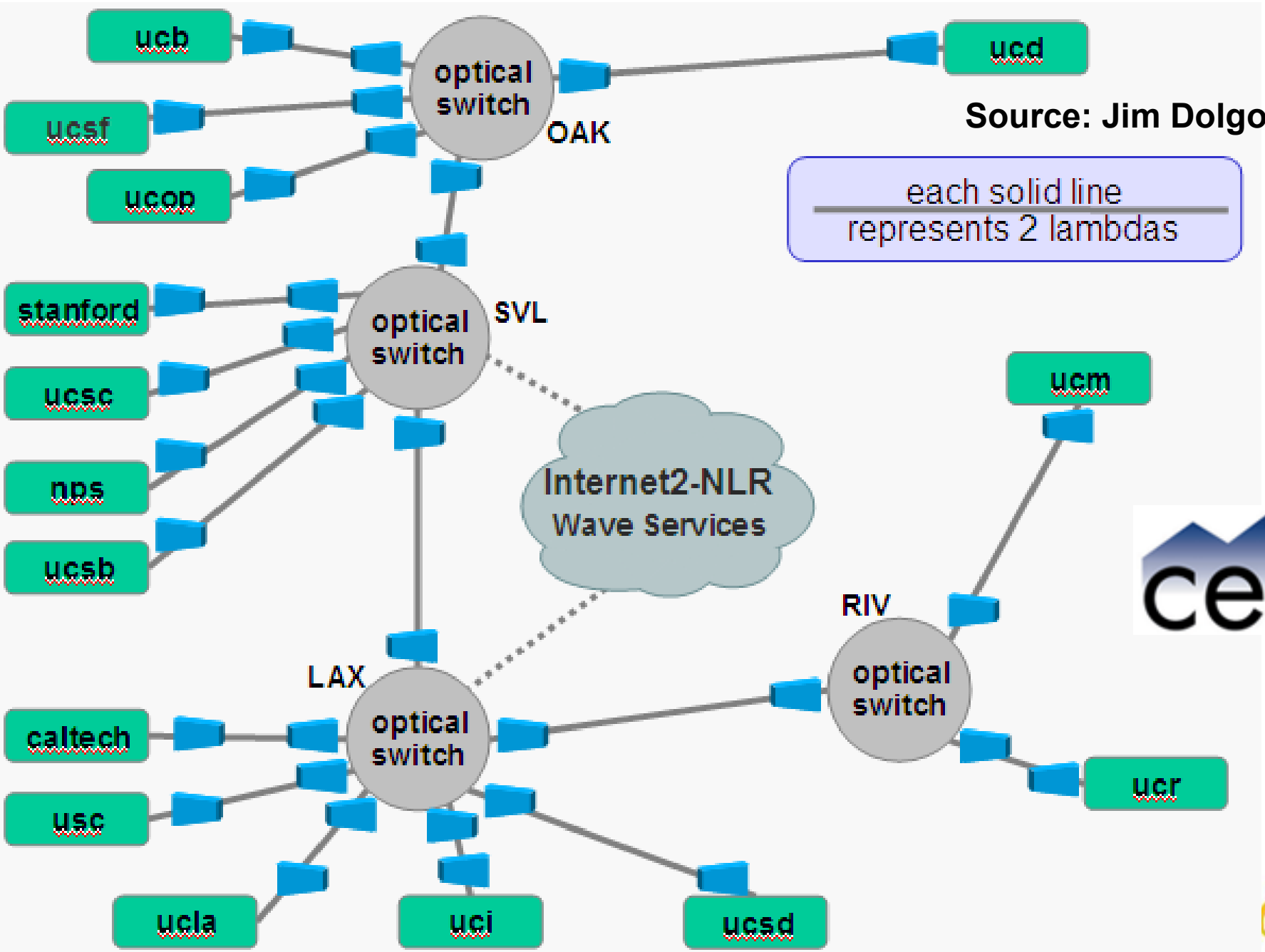
# CENIC Switched Ethernet Network
# HPRng-L2 Design



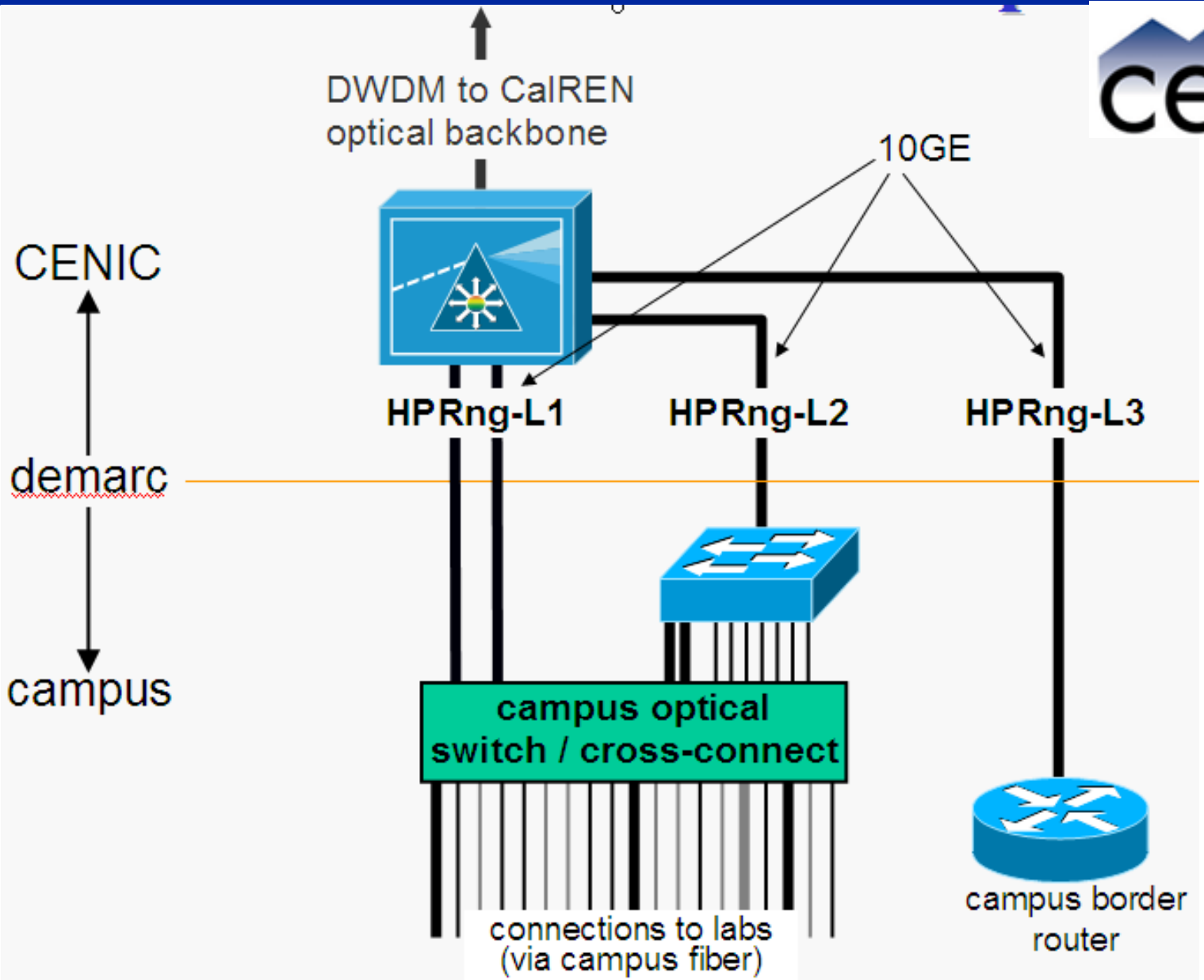

cenic

Source: Jim Dolgonas, CENIC

# CENIC Switched Optical Network
# HPRng-L1 design

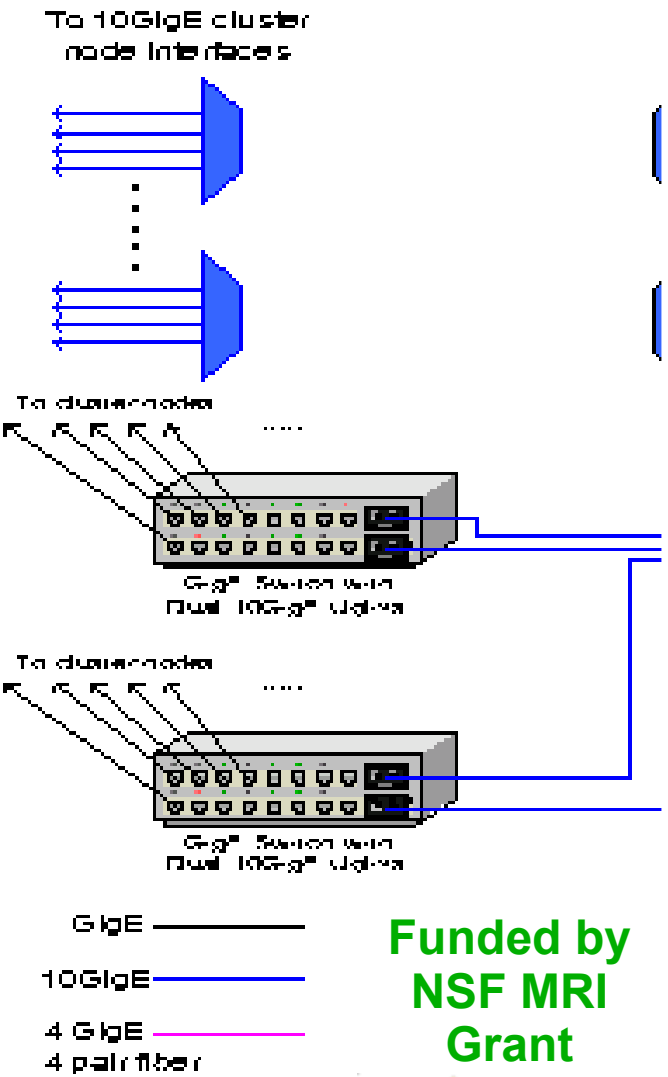


# Campus Preparations Needed to Accept CENIC CalREN Handoff to Campus




Source: Jim Dolgonas, CENIC

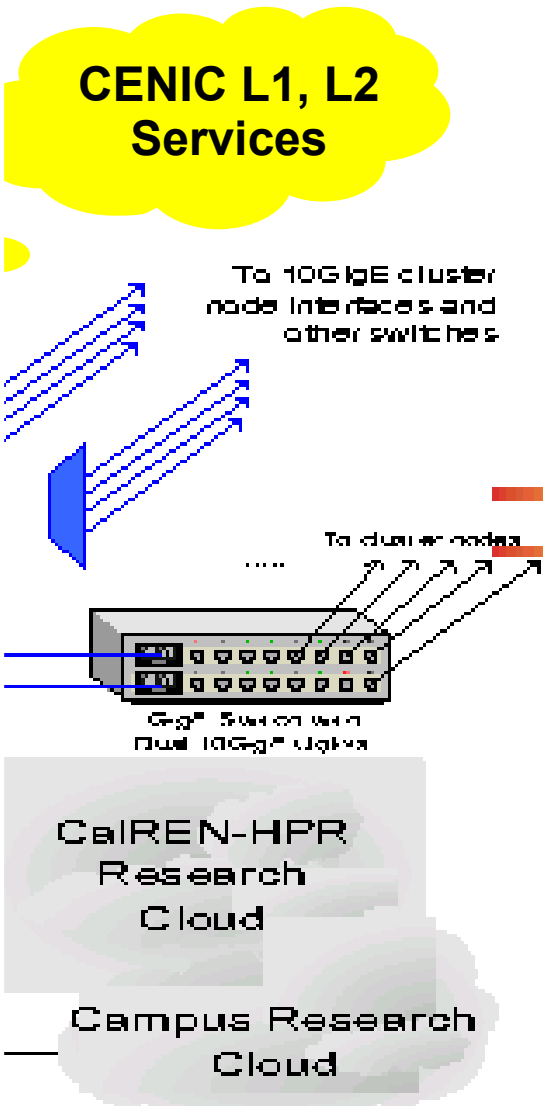
# Current UCSD Experimental Optical Core: Ready to Couple to CENIC L1, L2, L3 Services




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**




Funded by NSF MRI Grant

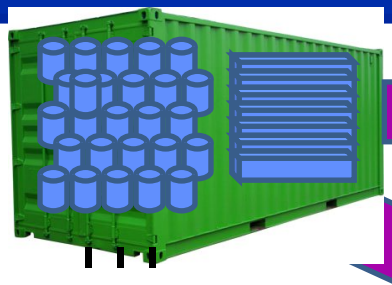
OptIPuter Border Router

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

UCSD UCIrvine

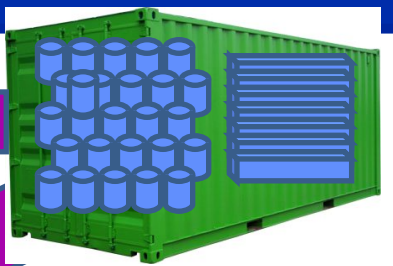
it2

# Planned UCSD Production Campus Cyberinfrastructure Supporting Data Intensive Biomedical Research



Active Data Replication

N x 10 Gbit



Eco-Friendly Storage and Compute

N x 10 Gbit

N x 10 Gbit



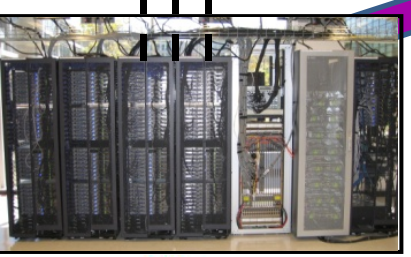
10 Gigabit L2/L3 Switch

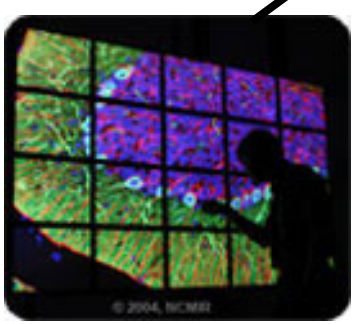
"Network in a box"
- > 200 Connections
- DWDM or Gray Optics

On-Demand Physical Connections

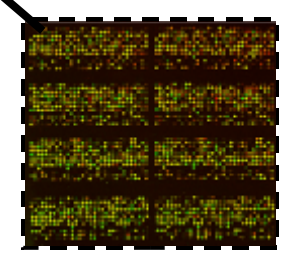
Wide-Area 10G
- CENIC/HPRng
- NLR Cavewave
- I2 NewNet
- Cinegrid
- …

Single 10 Gbit









Microarray

Your Lab Here

camera Marine Microbial Ecology

NCMIR NATIONAL CENTER for MICROSCOPY and IMAGING RESEARCH

NBCR

UCSD

UCIrvine

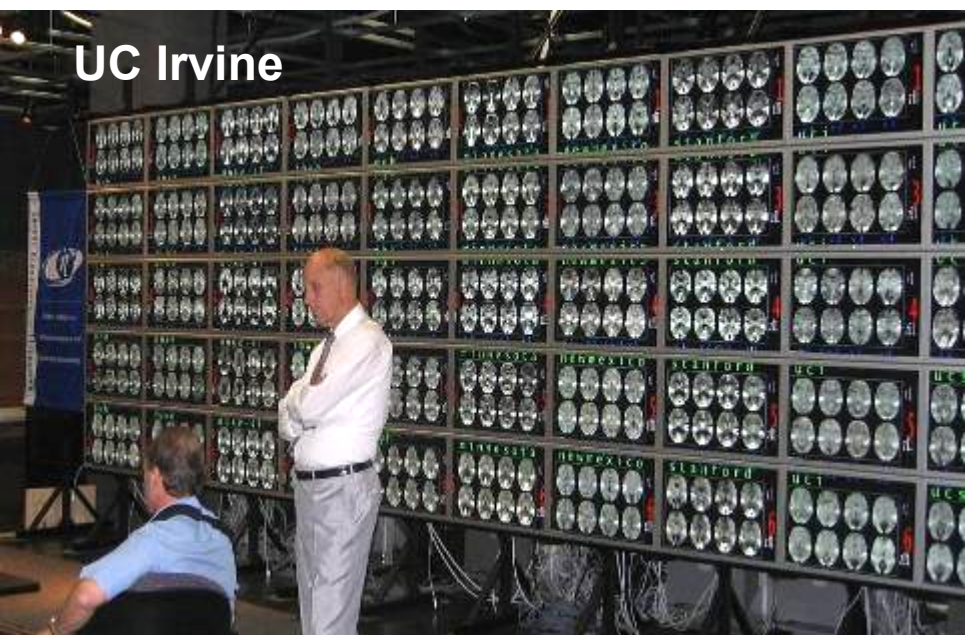
Source: Phil Papadopoulos, SDSC/Calit2; Elazar Harel, UCSD

it2

# Nearly One Half Billion Pixels in Calit2 Extreme Visualization Project!

**Connected at 2,000 Megabits/s!**



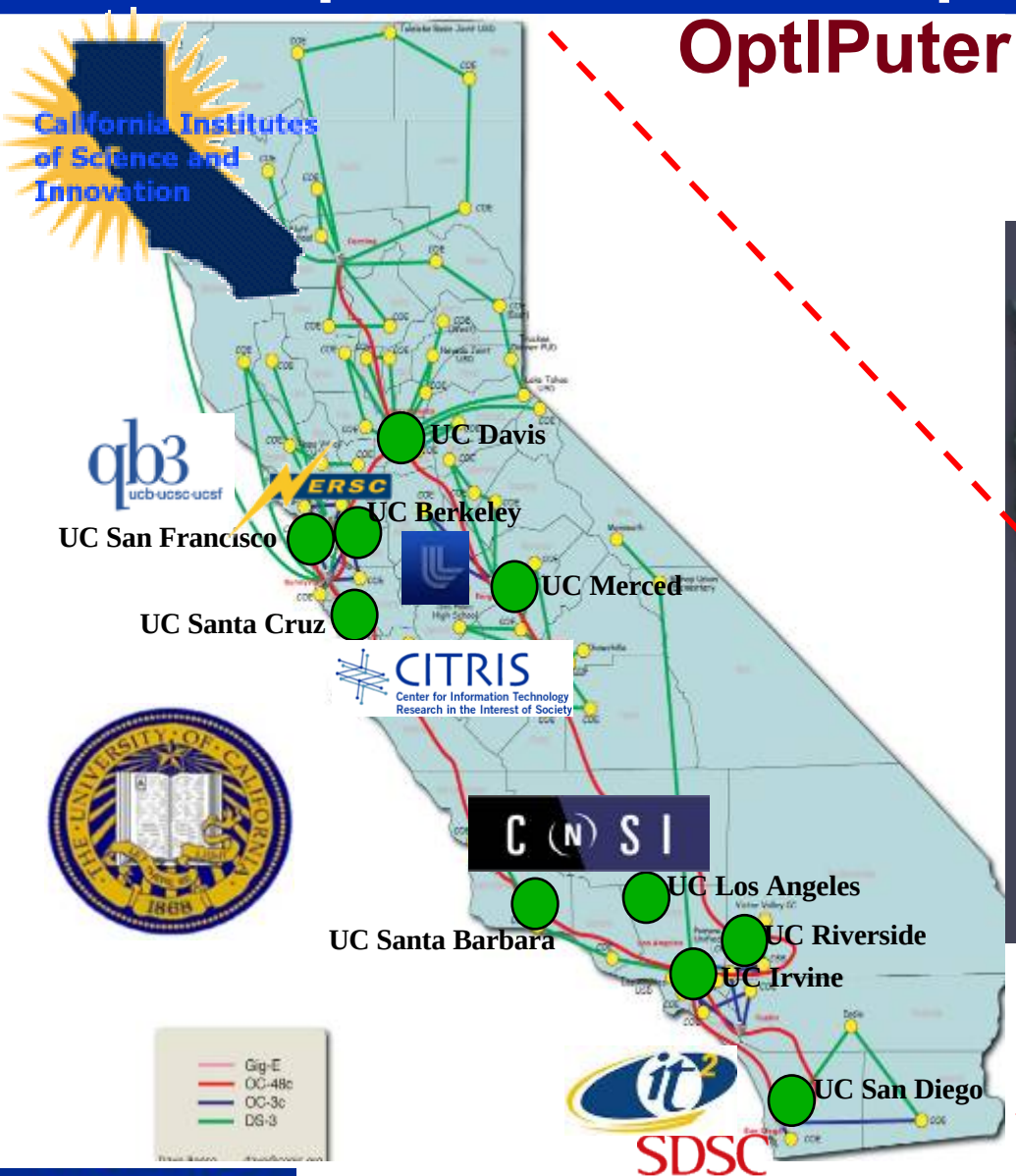



**UCI HIPerWall Analyzing Pre- and Post- Katrina**

UCSD
UCIrvine

**Falko Kuester, UCSD; Steven Jenks, UCI**

# Calit2/SDSC Proposal to Create a UC Cyberinfrastructure of OptIPuter "On-Ramps" to TeraGrid Resources




## OptIPuter + CalREN-XD + TeraGrid = "OptiGrid"




**Creating a Critical Mass of End Users on a Secure LambdaGrid**

UCSD
UCIrvine

Source: Fran Berman, SDSC , Larry Smarr, Calit2