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

Invited Talk
Naval Postgraduate School
Monterey, CA
March 27, 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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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 collaborative work environments, digital cinema, interactive ocean observatories, and marine microbial metagenomics.

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Calit2 Continues to Pursue Its Initial Mission:

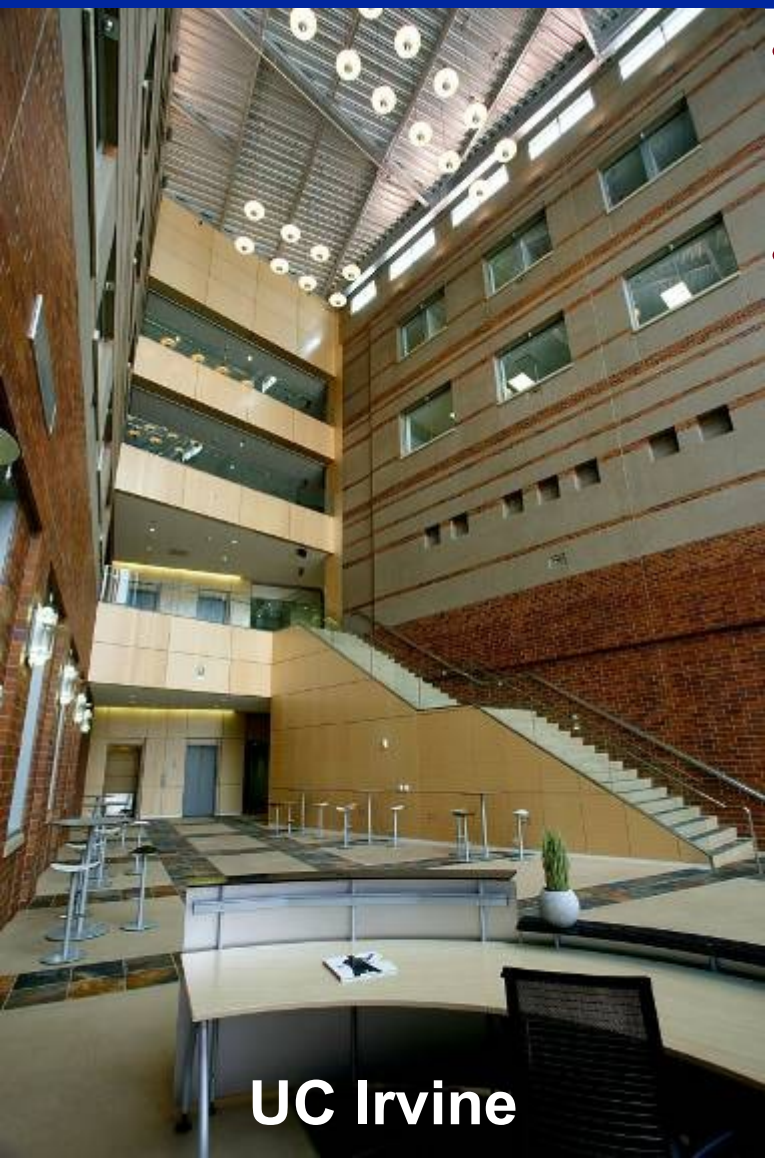
Envisioning How the Extension of Innovative Telecommunications and Information Technologies Throughout the Physical World will Transform Critical Applications Important to the California Economy and its Citizens' Quality Of Life.

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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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

Calit2 Has Pulled Together Over 300 Grants and 100 Companies

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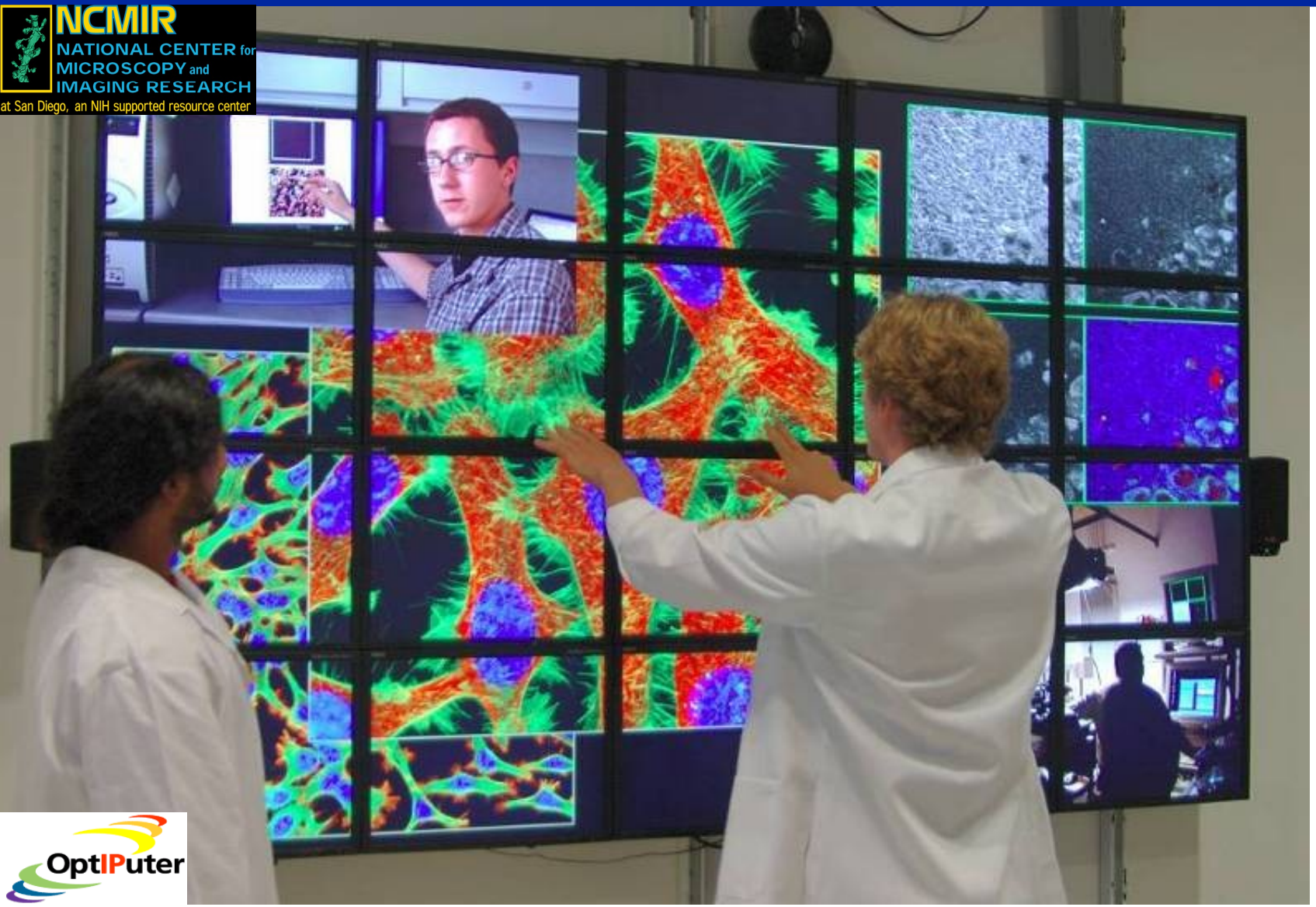
Calit2 Research Partnership with San Diego's SPAWAR

- **Calit2 / SPAWAR Cooperative Research Agreement**
  - **$15 Million Over 5 Years**
  - **UCSD Campus Wide—Administered by Calit2**
  - **Won Based on an Openly Advertised CFP**
  - **SPAWAR Can Quickly "Add a Researcher" to SPAWAR Research Grants**
- **Has Funded Over 40 Separate Projects During Five Years**
  - **Sixteen Professors From ECE, CSE, Calit2, CogSci, SIO, & BioSci**
    - **Signal Processing**
    - **Satellite, Wireless, Laser, and Fiber Networks**
    - **Remote Sensing**
    - **Security**
    - **Acoustics**
    - **Learning Tools**
    - **Buoy Design**
    - **Service Oriented Architectures…**

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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

$13.5M Over Five Years

Picture Source: Mark Ellisman, David Lee, Jason Leigh

OptIPuter

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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

it2

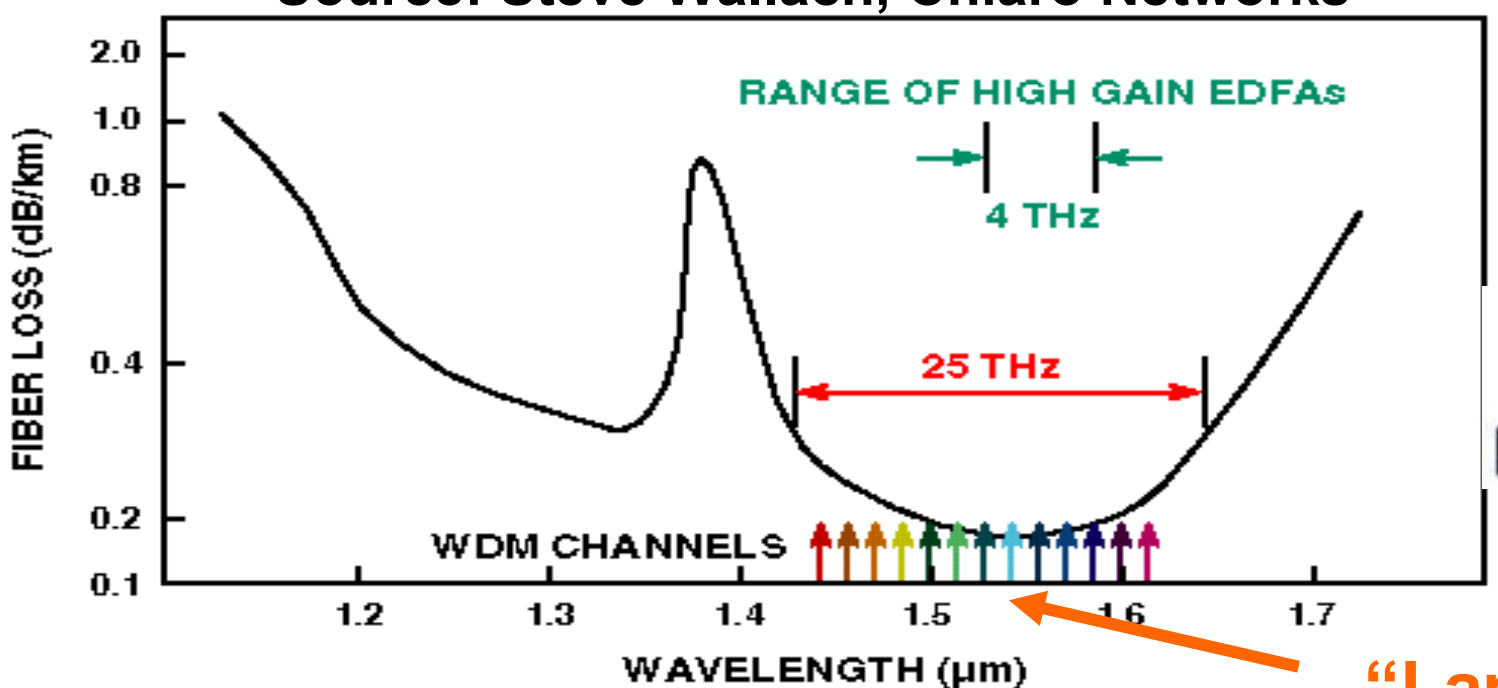
Dedicated Optical Channels Makes High Performance Cyberinfrastructure Possible

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

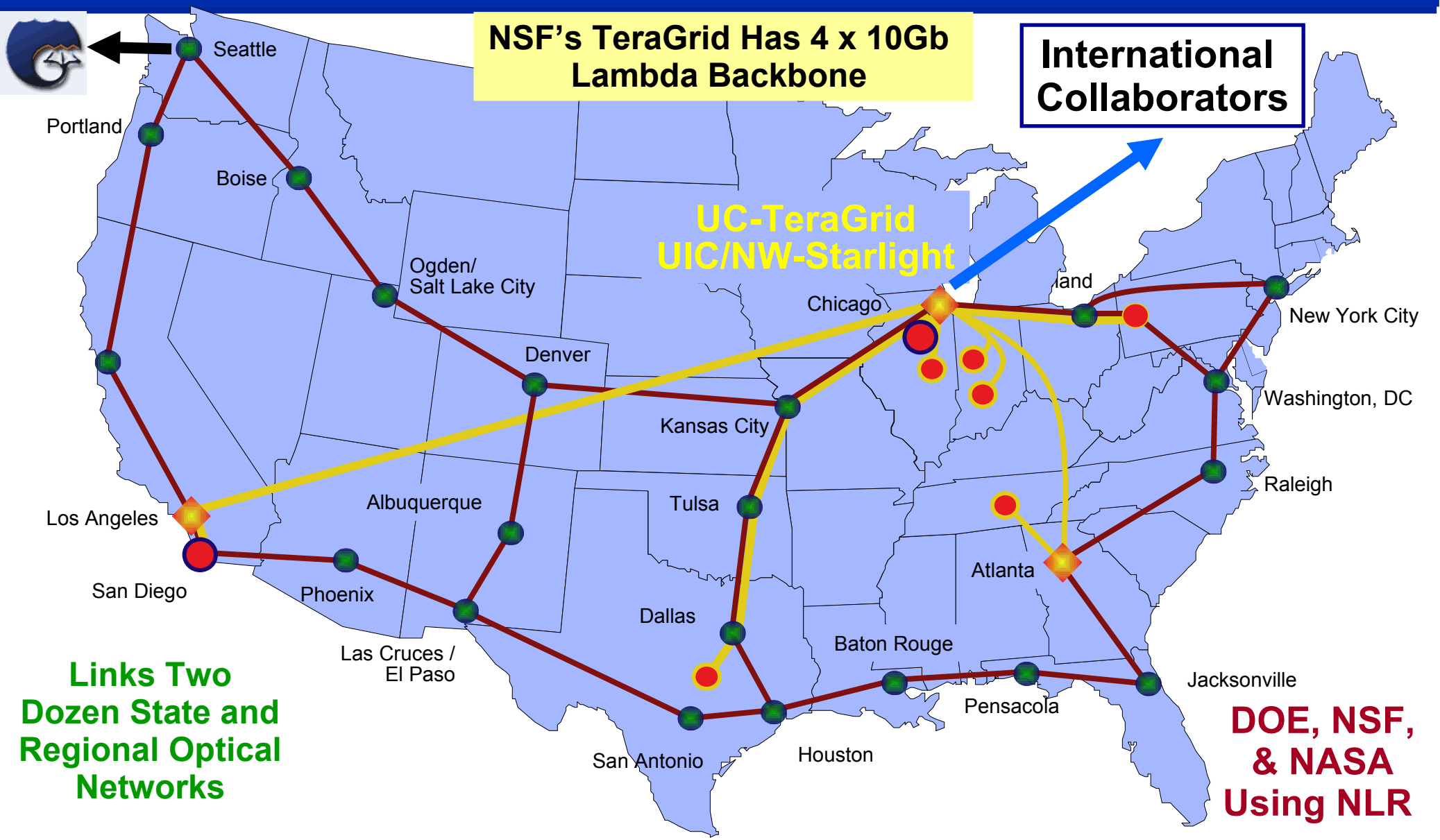
"Lambdas"

Single 10G Lightpath to Individual Users Enables Data-Intensive Science

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National Lambda Rail (NLR) and TeraGrid Provides Cyberinfrastructure Backbone for U.S. Researchers



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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

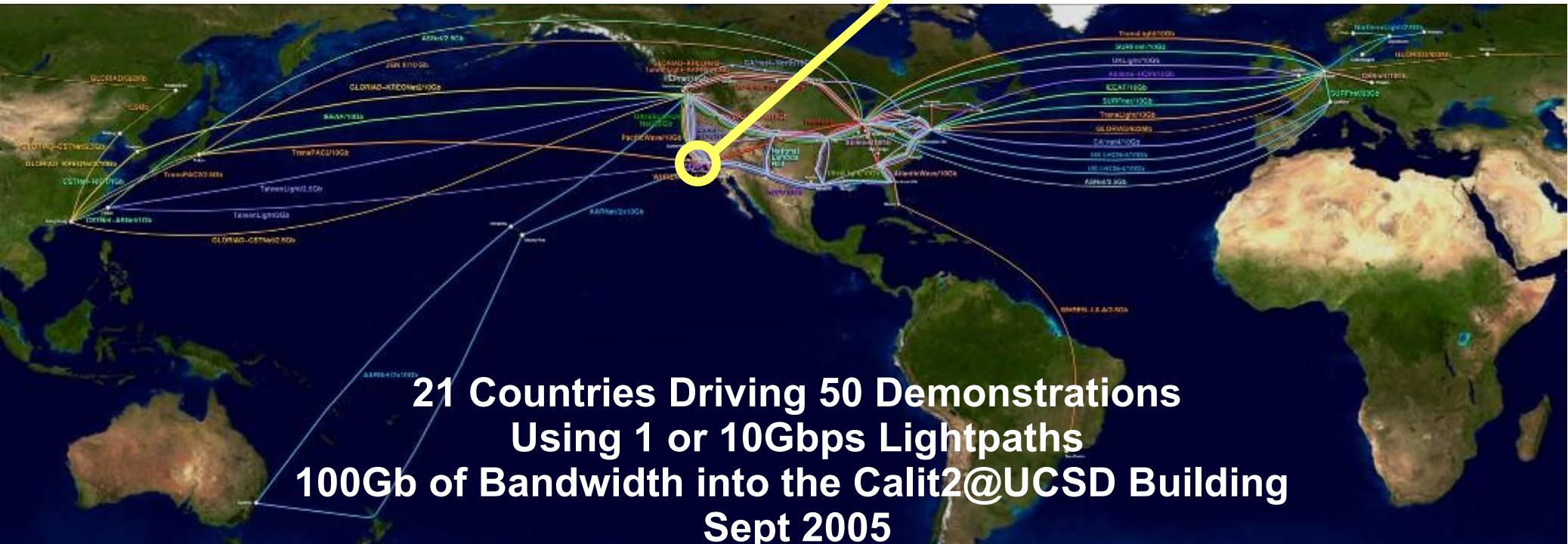


the UC Discovery Grant

September 26-30, 2005

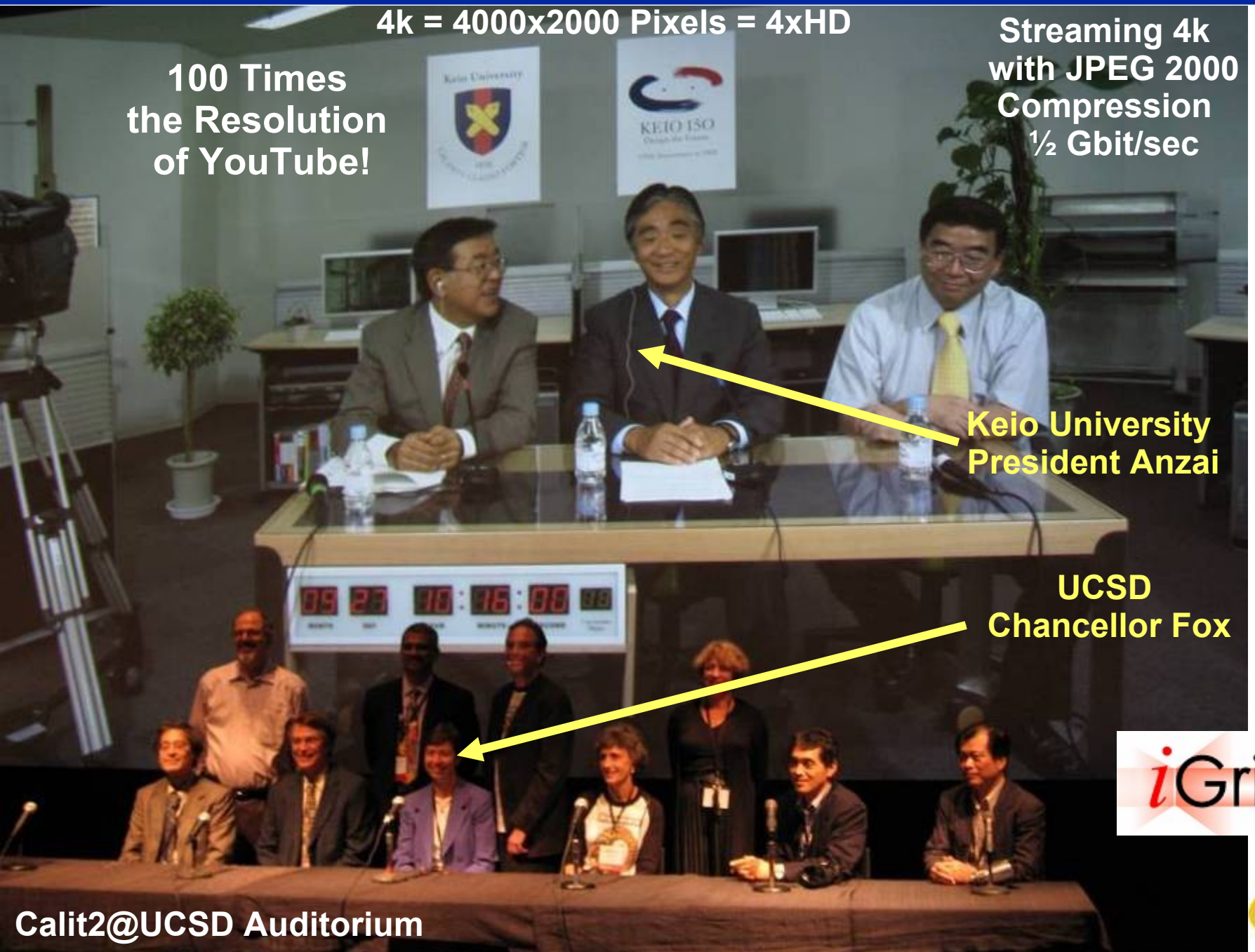
Calit2 @ University of California, San Diego

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

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



CineGrid™

Lays Technical Basis for Global Digital Cinema

Sony
NTT
SGI

iGrid 2005

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

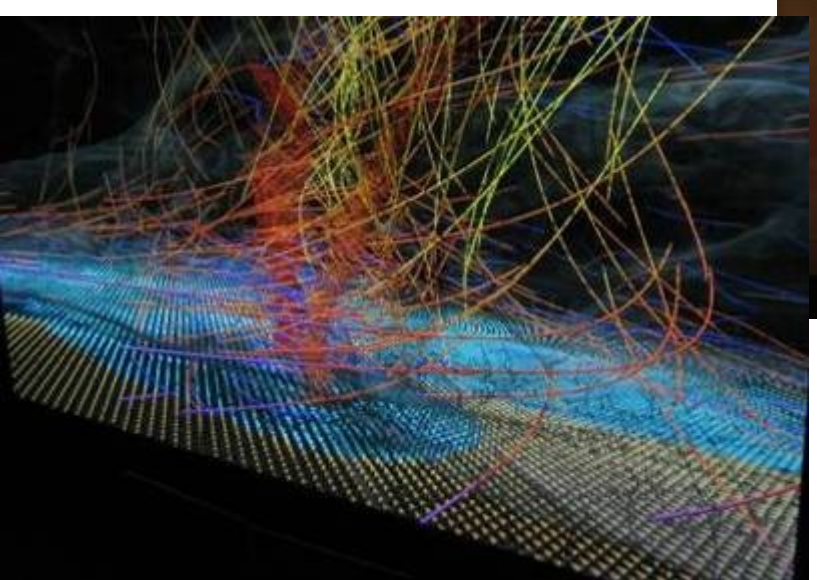
4K Distance Learning





4K Virtual Reality

4K Scientific Visualization





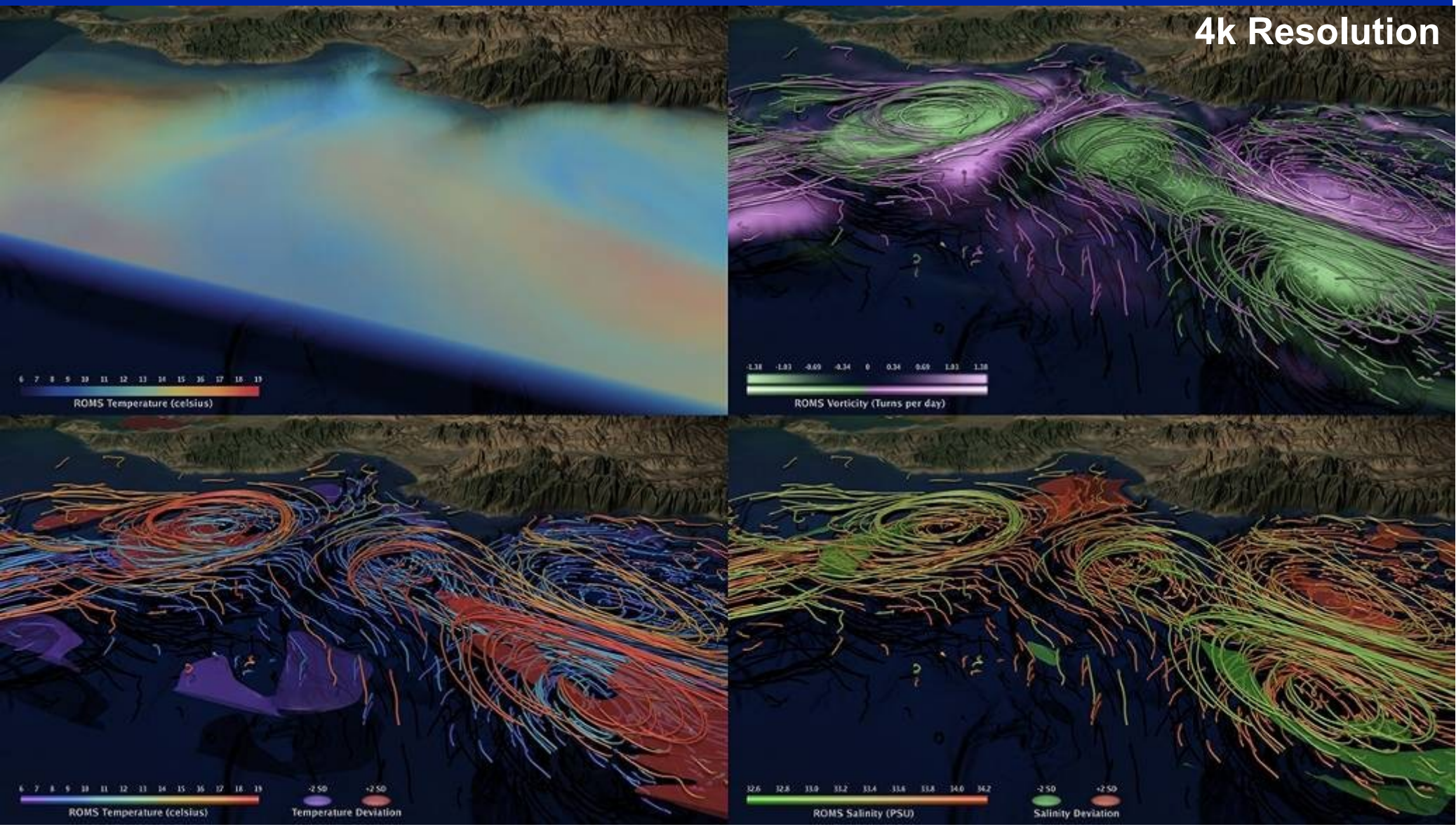
4K Digital Cinema

4K *Anime*



Source: Laurin Herr

From Digital Cinema to Scientific Visualization: JPL Simulation of Monterey Bay



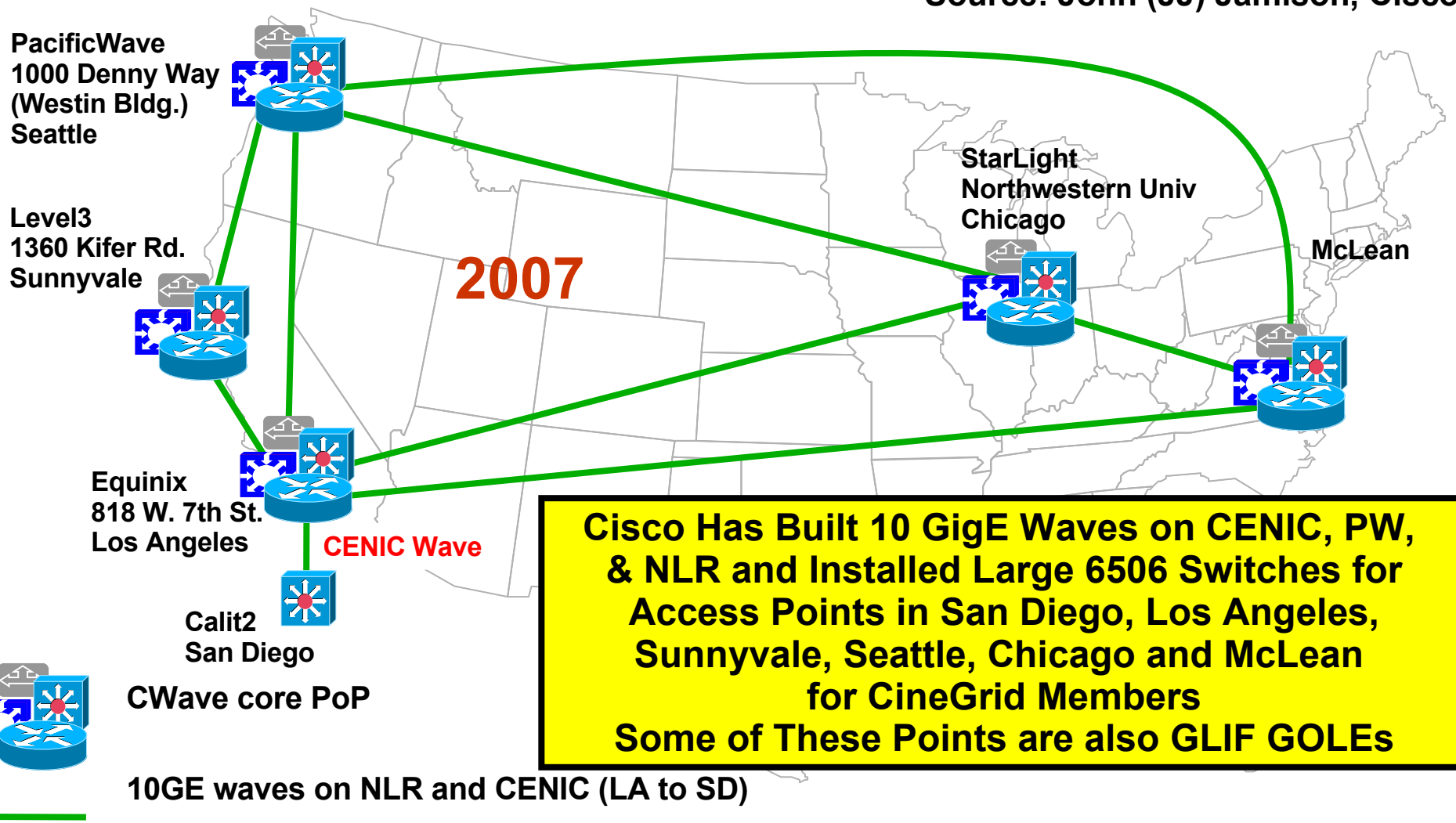
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Source: Donna Cox, Robert Patterson, NCSA
Funded by NSF LOOKING Grant

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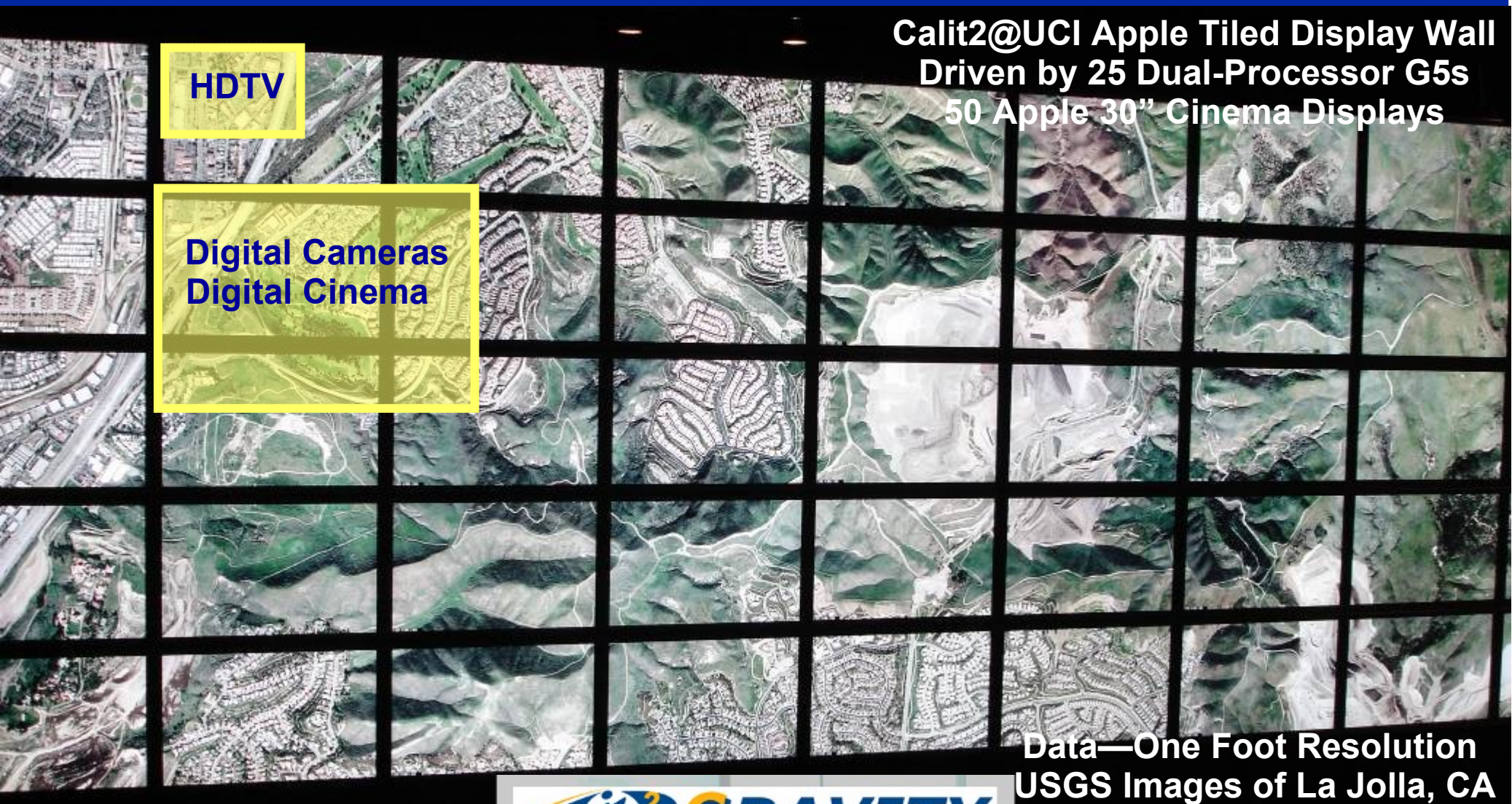
Cisco CWave for CineGrid: A New Cyberinfrastructure for High Resolution Media Streaming*

Source: John (JJ) Jamison, Cisco



Cisco Has Built 10 GigE Waves on CENIC, PW, & NLR and Installed Large 6506 Switches for Access Points in San Diego, Los Angeles, Sunnyvale, Seattle, Chicago and McLean for CineGrid Members
Some of These Points are also GLIF GOLEs

Beyond 4k –
From 8 Megapixels Towards a Billion Pixels



it² Center of GRAVITY
Center of Graphics, Visualization and Imaging Technology

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Source: Falko Kuester, Calit2@UCI
NSF Infrastructure Grant

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Multi-Gigapixel Images are Available from Film Scanners Today



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The Gigapxl Project
http://gigapxl.org

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Large Image with Enormous Detail Requires Interactive OptIPortal Systems



The OptIPuter Project Works with a Wide Range of >100M Pixel Images

One Square Inch Shot From 100 Yards

High Resolution Aerial Photography Generates Images With 10,000 Times More Data than Landsat7

Landsat7 Imagery
100 Foot Resolution
Draped on elevation data





New USGS Aerial Imagery
At 1-Foot Resolution

~10x10 square miles of 350 US Cities
2.5 Billion Pixel Images Per City!

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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 of NASA Space Observatories

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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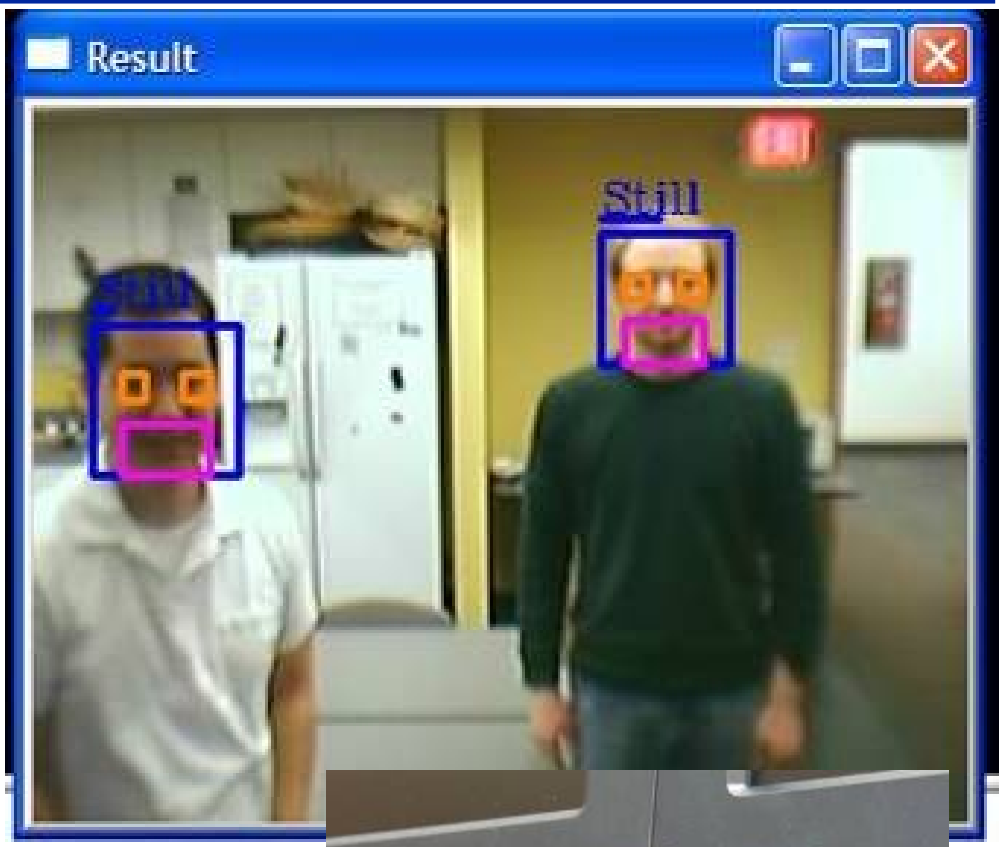
Powered by Rocks ROCKS

Source: Phil Papadopoulos SDSC, Calit2

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U Michigan Virtual Space Interaction Testbed (VISIT) Instrumenting OptIPortals for Social Science Research

- Using Cameras Embedded in the Seams of Tiled Displays and Computer Vision Techniques, we can Understand how People Interact with OptIPortals
  - Classify Attention, Expression, Gaze
  - Initial Implementation Based on Attention Interaction Design Toolkit (J. Lee, MIT)
- Close to Producing Usable Eye/Nose Tracking Data using OpenCV





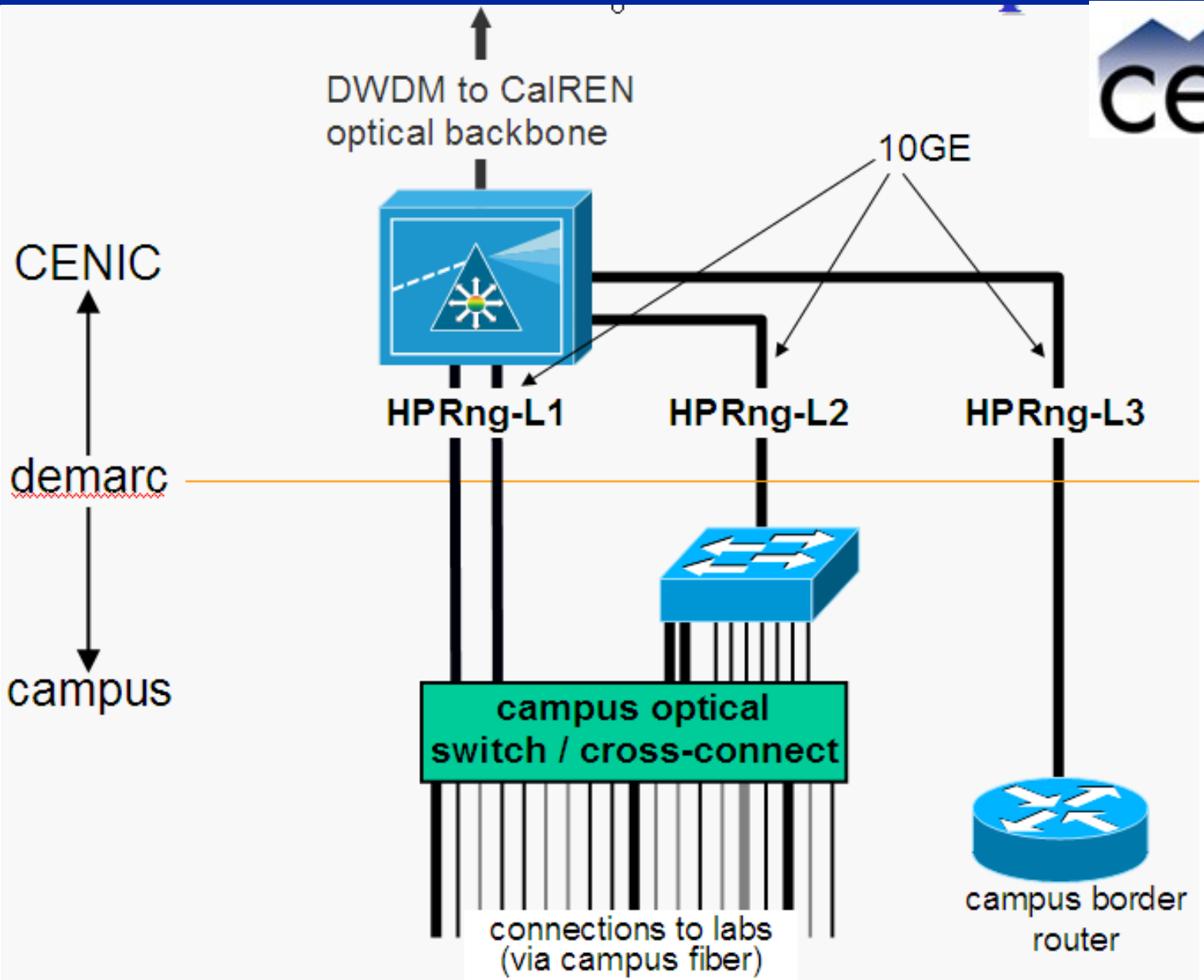
Leading U.S. Researchers on the Social Aspects of Collaboration

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Source: Erik Hofer, UMich, School of Information

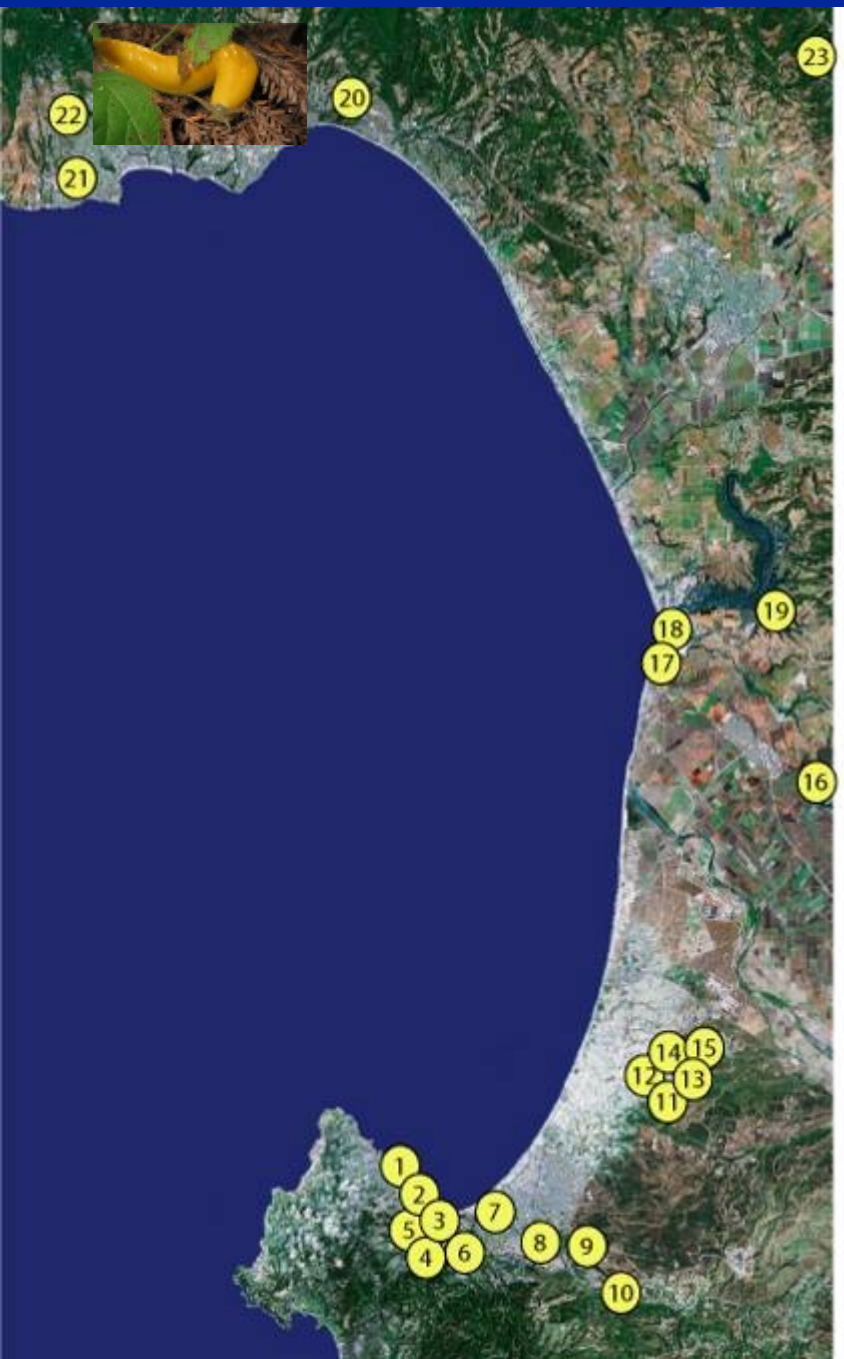
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Campus Preparations Needed to Accept CENIC CalREN Handoff to Campus



Source: Jim Dolgonas, CENIC

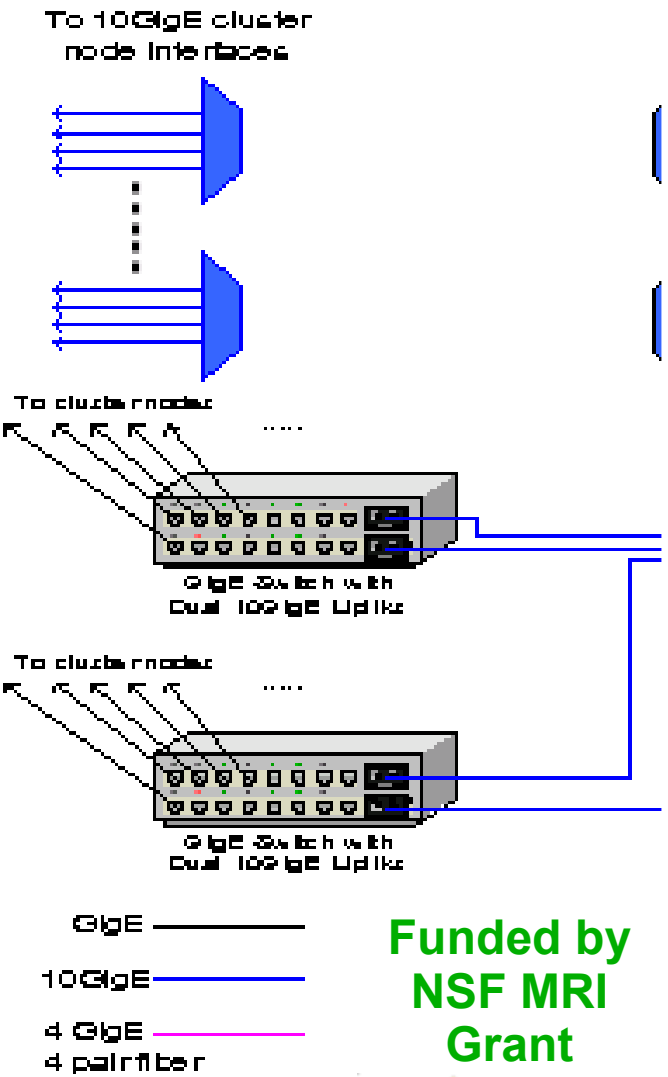
Great Opportunity to Bring CENIC 10Gbps Fiber to Monterey Bay Research & Education Institutions



Higher Education and Research Institutions of the Monterey Bay

1. Hopkins Marine Station, Stanford University
2. Monterey Bay Aquarium
3. National Oceanic and Atmospheric Administration
4. Monterey Institute of International Studies
5. Defense Language Institute
6. Monterey Peninsula College
7. Naval Postgraduate School
8. Naval Research Laboratory
9. Fleet Numerical Meteorology and Oceanography Center
10. California Department of Fish and Game
11. Defense Manpower Data Center
12. Monterey College of Law
13. Golden Gate University
14. California State University Monterey Bay
15. Panetta Institute
16. Hartnell College - Salinas
17. Moss Landing Marine Laboratory, CSU
18. Monterey Bay Aquarium Research Institute
19. Elkhorn Slough National Estuarine Research Reserve
20. Cabrillo College
21. United States Geological Survey
22. UC Santa Cruz
23. Gavilan College - Gilroy

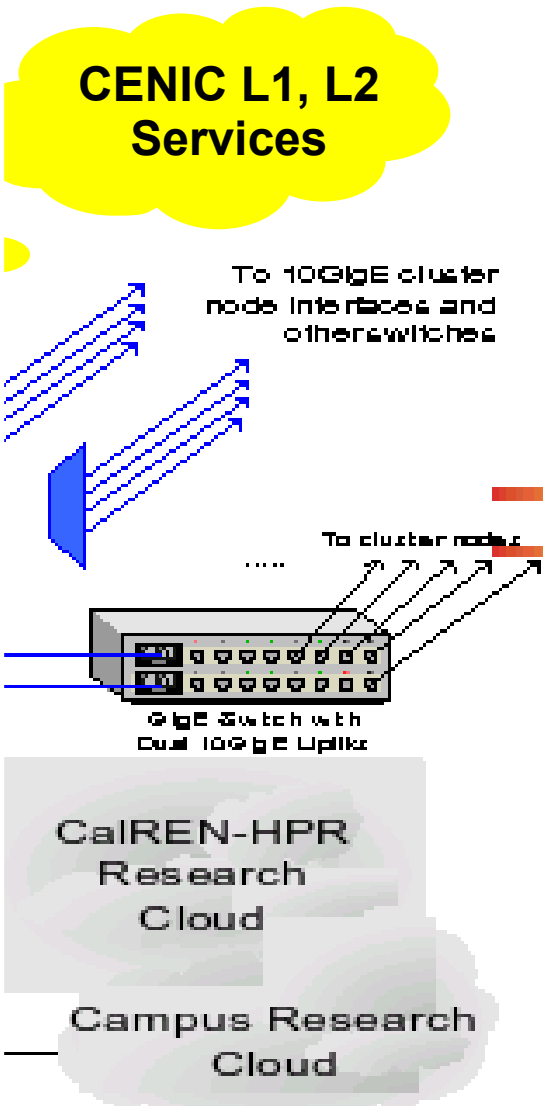
Current UCSD Experimental Optical Core: Ready to Couple to CENIC L1, L2, L3 Services



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

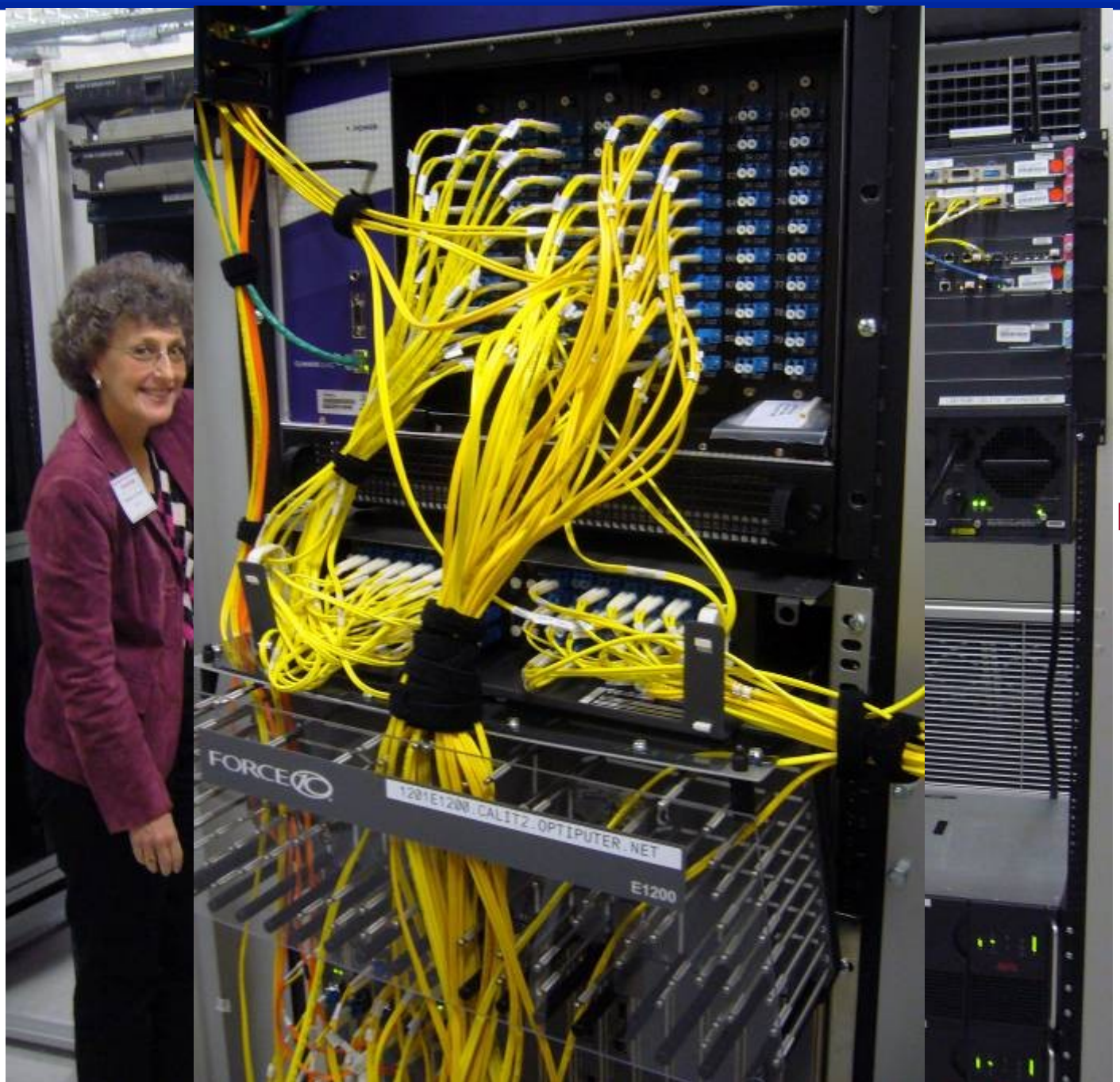


Funded by NSF MRI Grant

OptIPuter Border Router

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

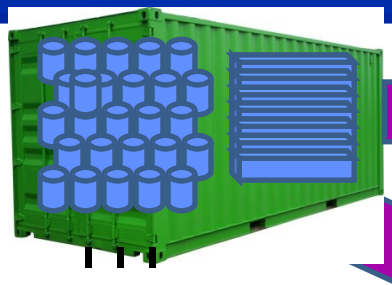
Calit2 Sunlight Optical Exchange Contains Quartzite



10:45 am
Feb. 21, 2008

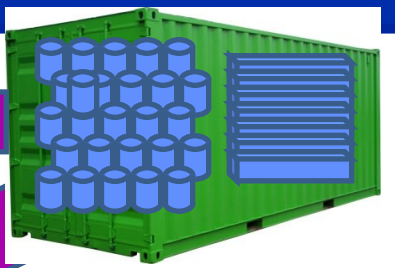
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Planned UCSD Production Campus Cyberinfrastructure Supporting Data Intensive Biomedical Research



Active Data Replication

N x 10 Gbit



Eco-Friendly Storage and Compute

N x 10 Gbit

N x 10 Gbit



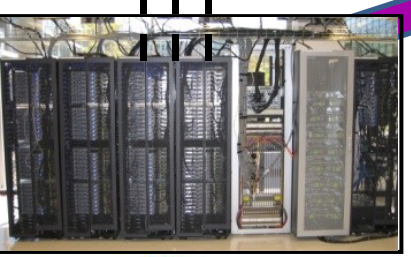
10 Gigabit L2/L3 Switch

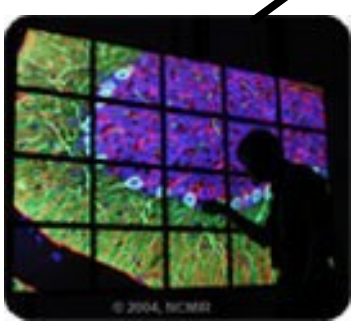
"Network in a box"
- > 200 Connections
- DWDM or Gray Optics

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

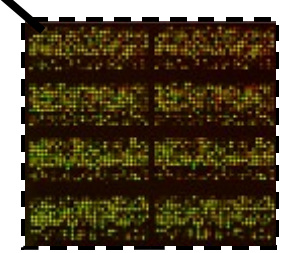
Single 10 Gbit

On-Demand Physical Connections









Microarray

Your Lab Here

camera
Marine Microbial Ecology

NCMIR
NATIONAL CENTER for MICROSCOPY and IMAGING RESEARCH

NBCR

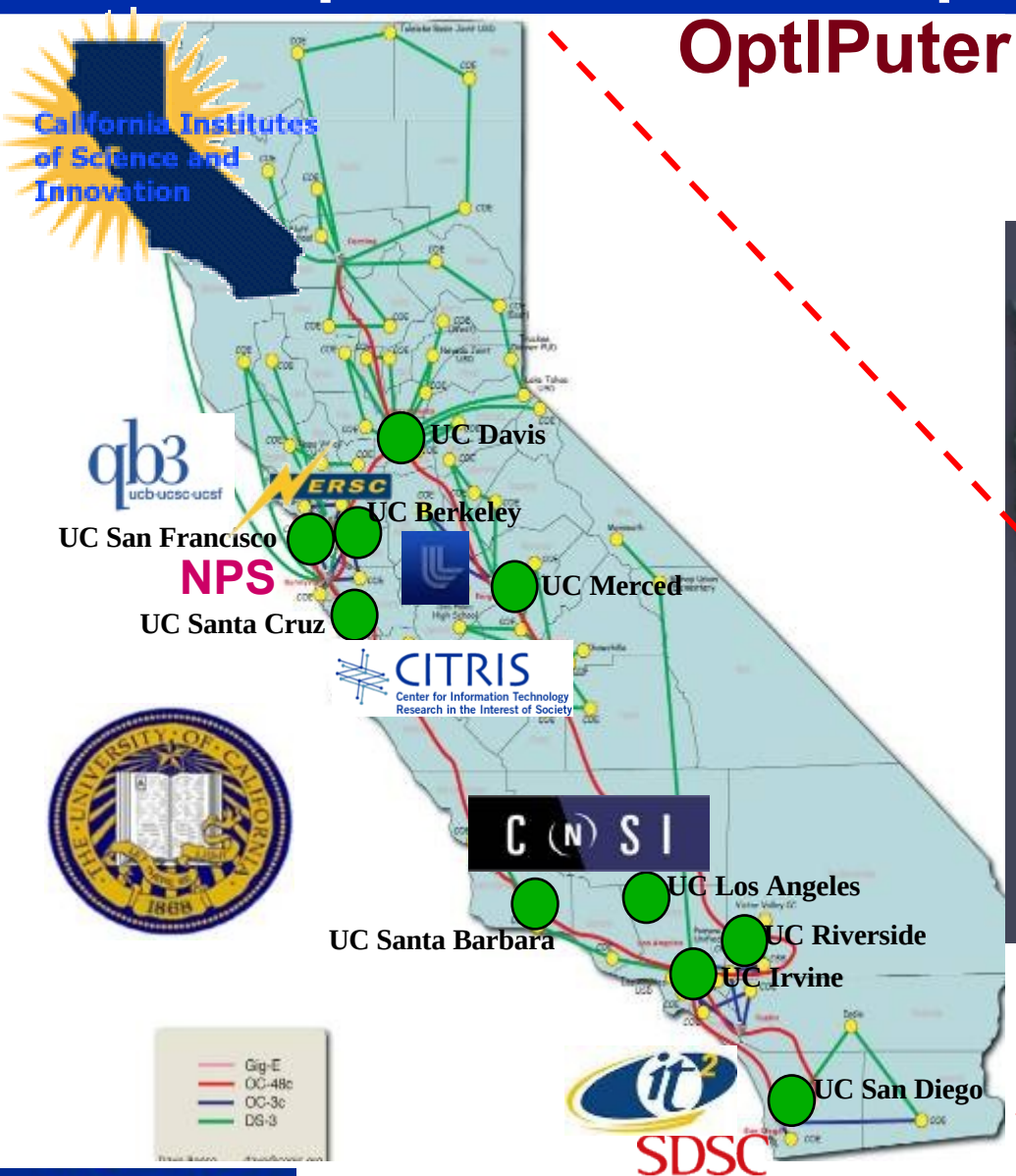
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Source: Phil Papadopoulos, SDSC/Calit2; Elazar Harel, UCSD

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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

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Source: Fran Berman, SDSC , Larry Smarr, Calit2

MAP '06 System Configuration

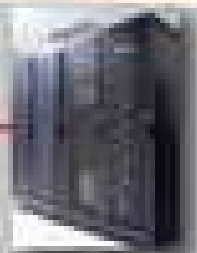
DISTRIBUTED COMPUTING NODES



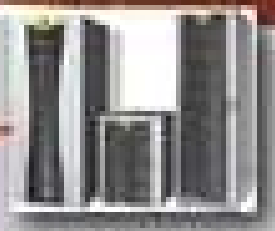
INTEL Corp
Portland, Oregon



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)

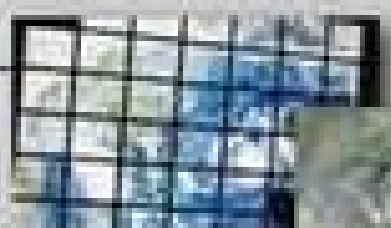
CISTO (GSFC) &
GES DAAC DATA
PORTALS



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)



EXTERNAL
COLLABORATORS

FSU
Meteorology

NASA

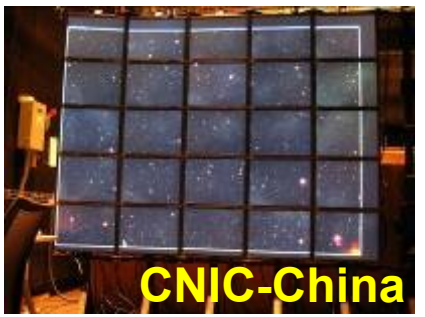
G. McConaughy (585), B. Womack (Northrop), P. Webster (606), D. Duffy (CSC), M. Whitehead (CSC), H. Michel (610.3), J. Delabeaujardiere (610.3), R. Jones (GST)

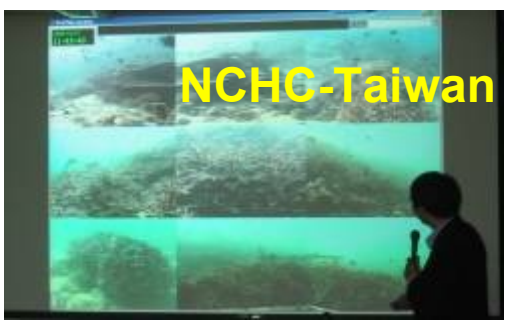
Rocks / SAGE OptIPortals Are Being Adopted Globally


AIST-Japan


KISTI-Korea

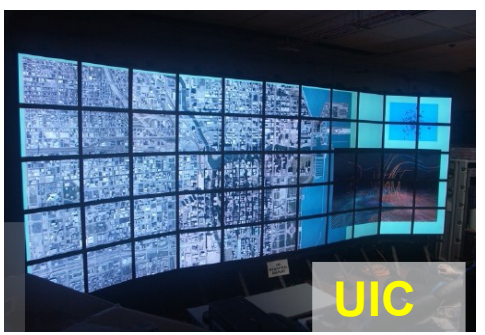

UZurich


CNIC-China


NCHC-Taiwan


Osaka U-Japan

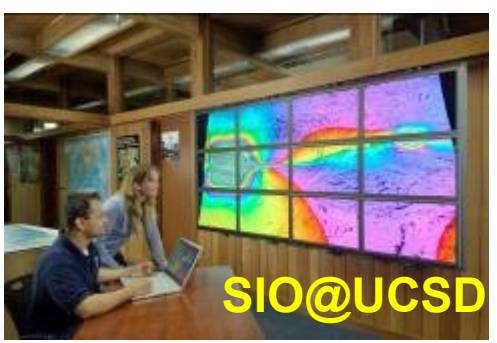

NCSA & TRECC


UIC


Calit2@UCI


Calit2@UCSD


NCMIR@UCSD

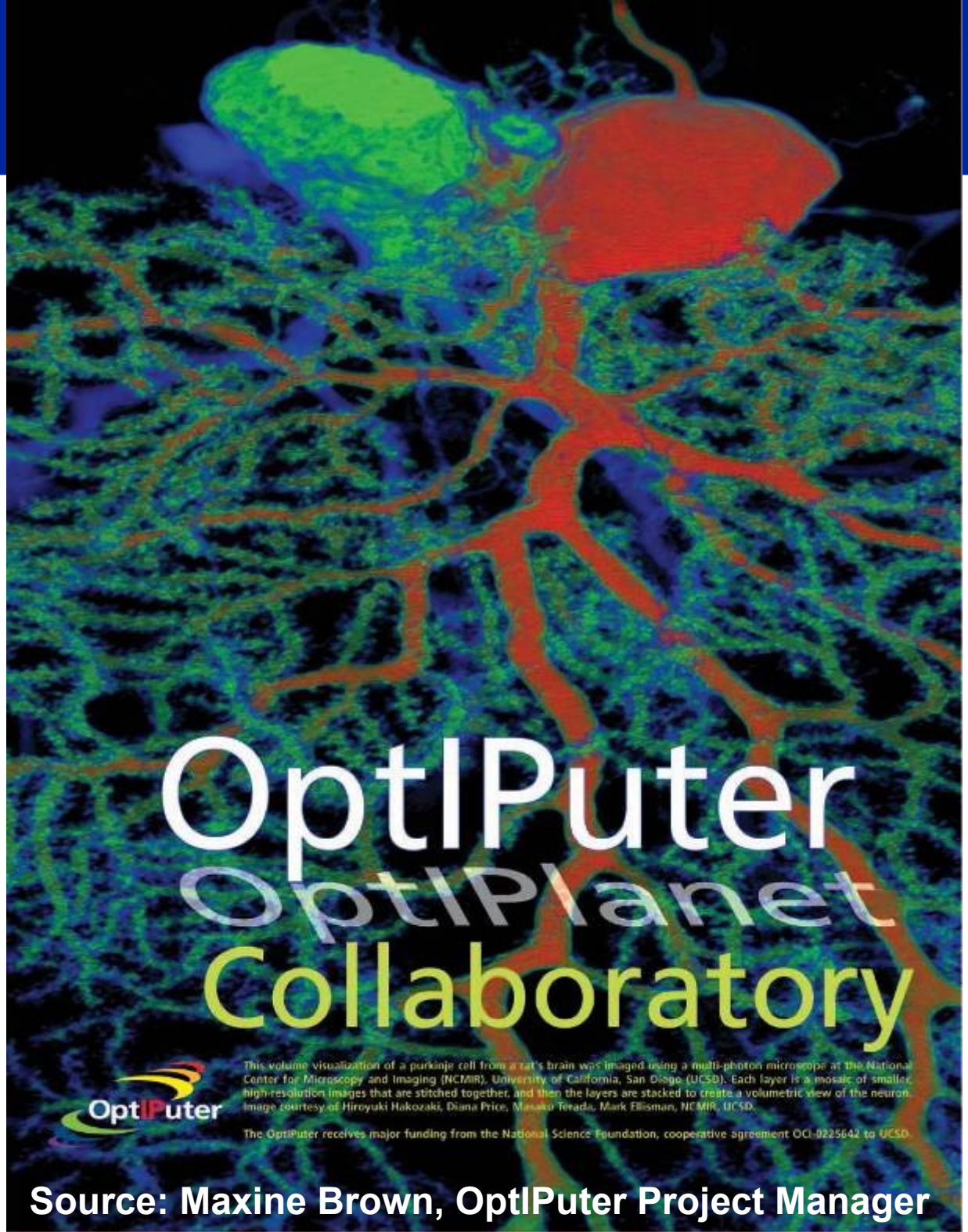

SIO@UCSD

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Powered by Rocks ROCKS

evl electronic visualization laboratory

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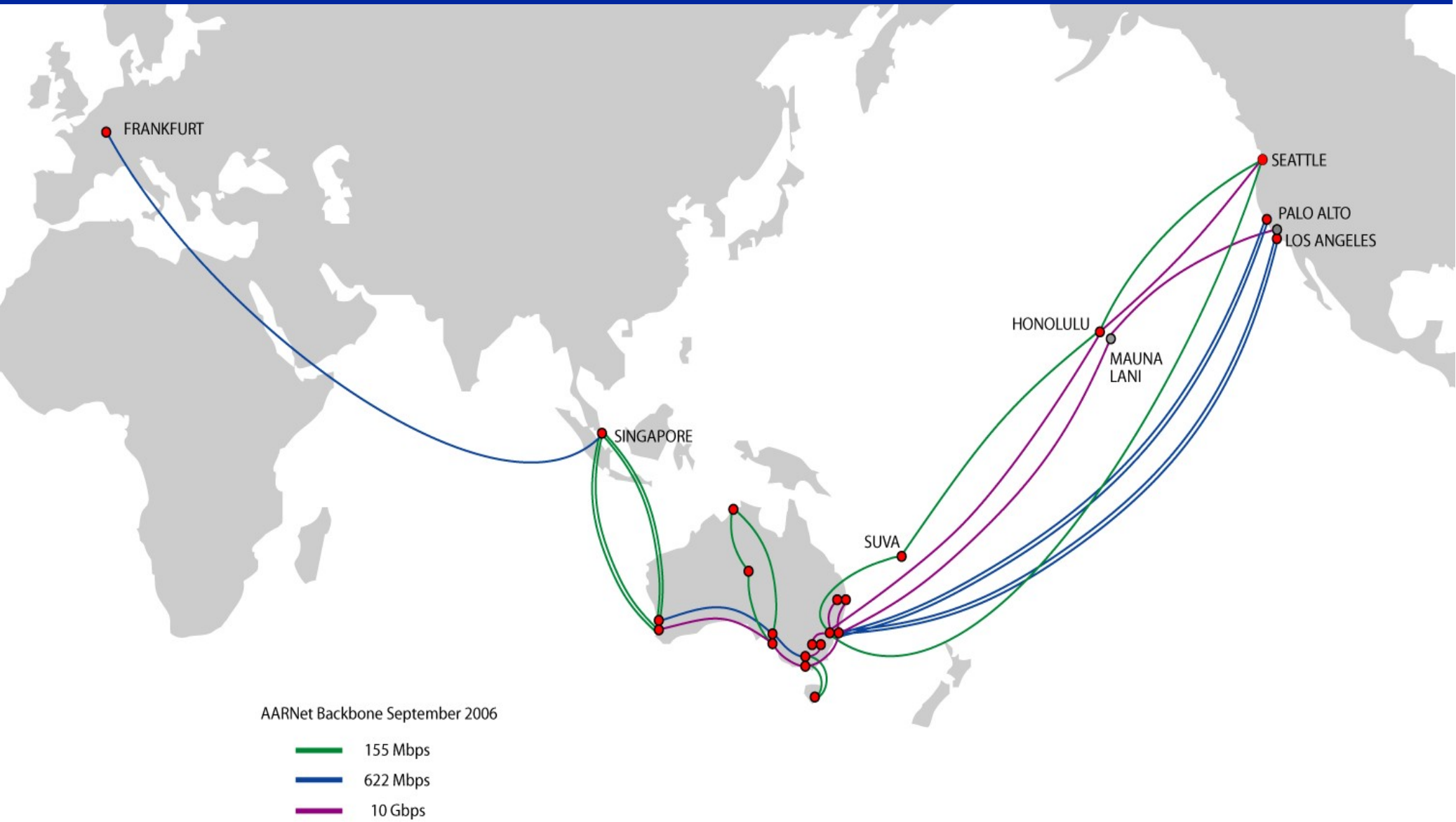
Source: Maxine Brown, OptIPuter Project Manager

Green Initiative:

Can Optical Fiber Replace Airline Travel for Continuing Collaborations ?

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Adding Australia to the OptIPlanet Collaboratory via AARNet International Optical Fiber Network



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“Using the Link to Build the Link”
Calit2 and Univ. Melbourne Technology Teams



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

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

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



January 15, 2008

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

Victoria Premier and Australian Deputy Prime Minister Asking Questions of Calit2 Audience



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

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Calit2, SDSC, and SIO are Creating Environmental Observatories



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NSF-Funded ROADnet and HiSeasNet are Prototypes of the Future of *In Situ* Earth Observing Systems



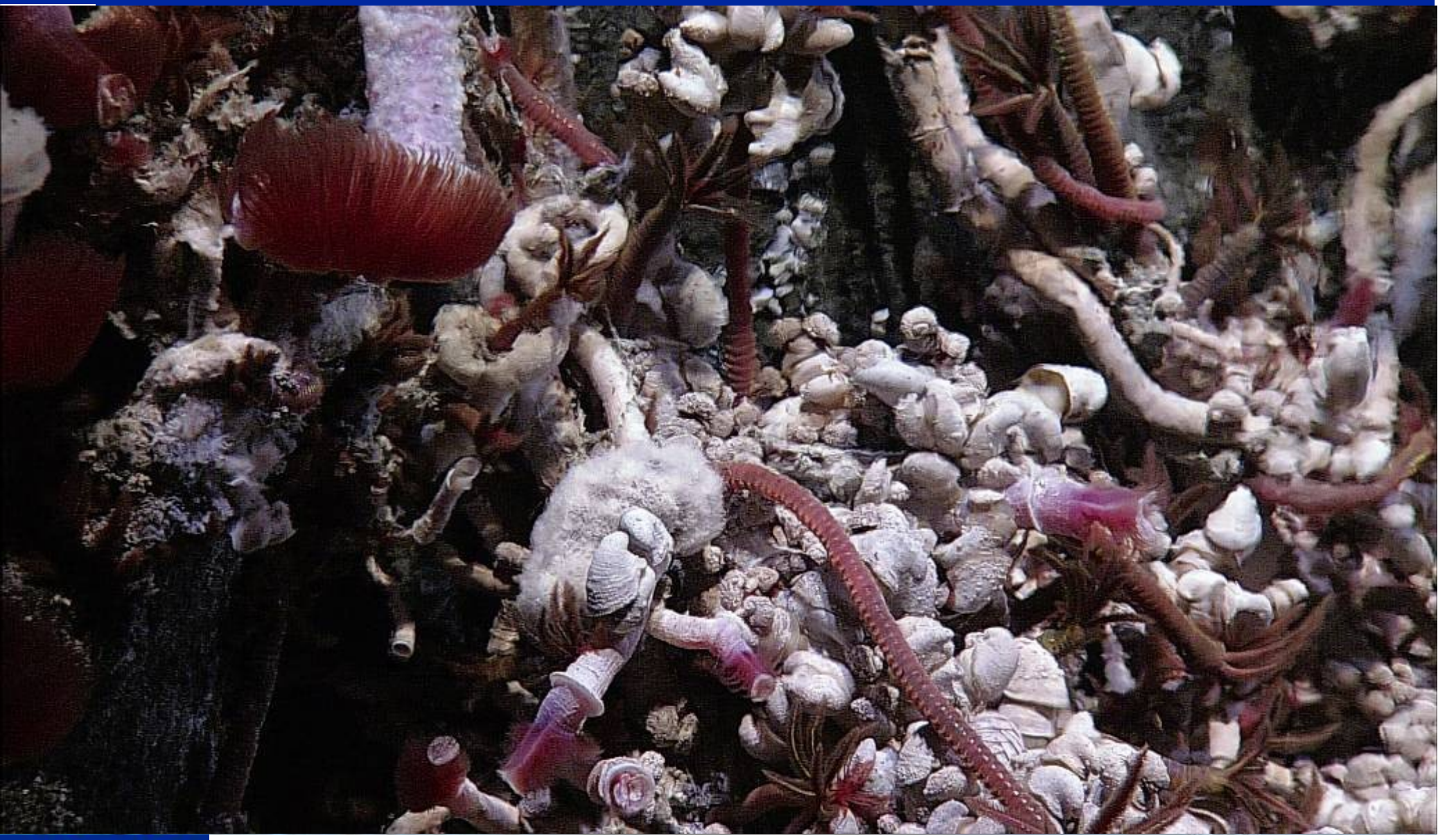
HiSeasNet

The Real-time Observatories, Applications and Data management Network is an interdisciplinary collaboration funded by the National Science Foundation and the Office of Naval Research. Participating institutions include Scripps Institution of Oceanography and the San Diego Supercomputer Center at the University of California, San Diego.

jonathan berger, john orcutt, frank vernon, scripps institution of oceanography, university of california san diego

PROVIDING COMMUNICATIONS AND NETWORKING FOR THE ORION FLEET OF MOORED OCEAN OBSERVATORIES

Remote Interactive High Definition Video of Deep Sea Hydrothermal Vents



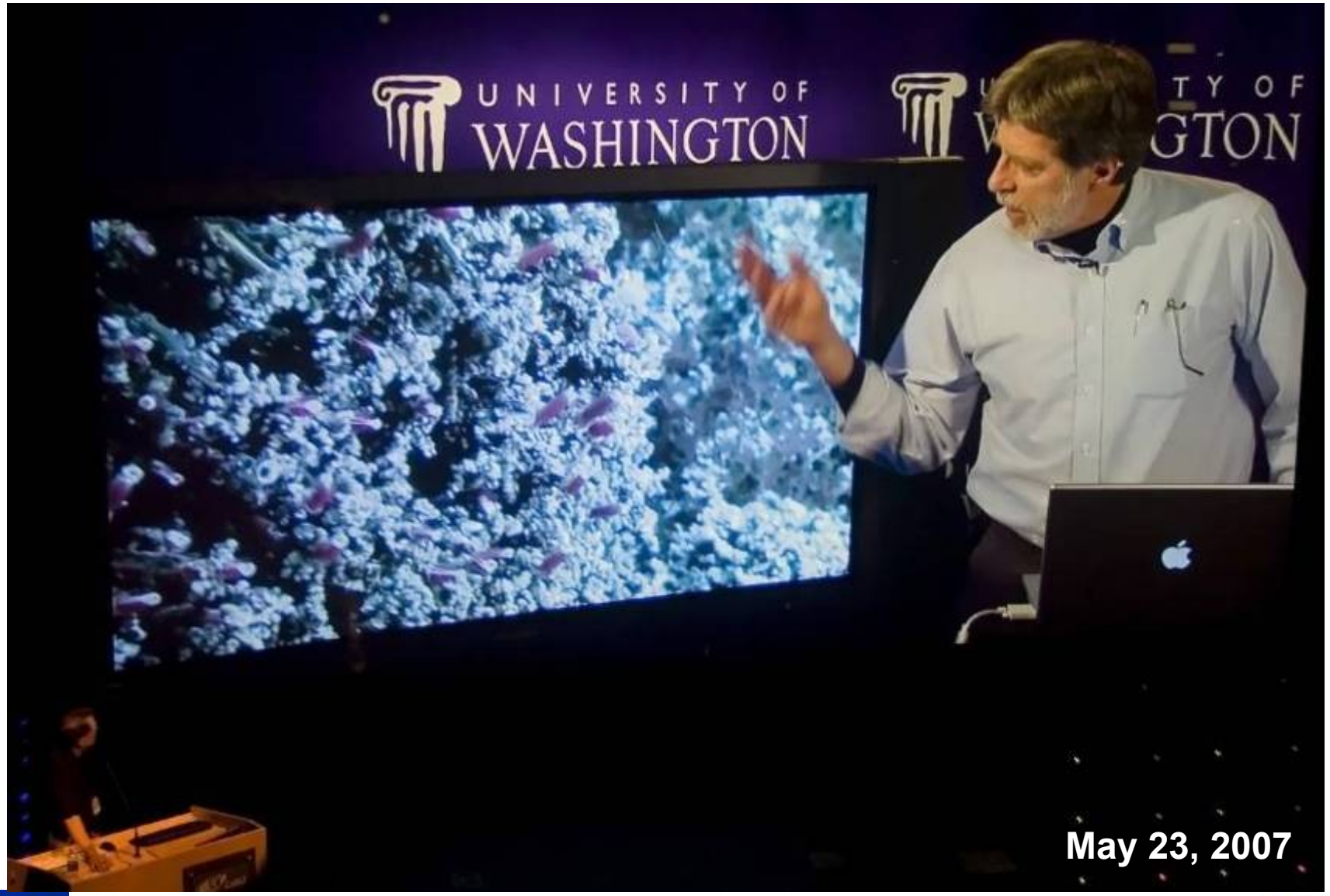
UCSD
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Source John Delaney & Deborah Kelley, UWash

it²

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

1500 Mbits/sec Calit2 to UW Research Channel Over NLR



John Delaney, PI LOOKING, Neptune

Photo: Harry Ammons, SDSC

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OptIPlanet Collaboratory Persistent Infrastructure Between Calit2 and U Washington



OptIPuter

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

ROCKS







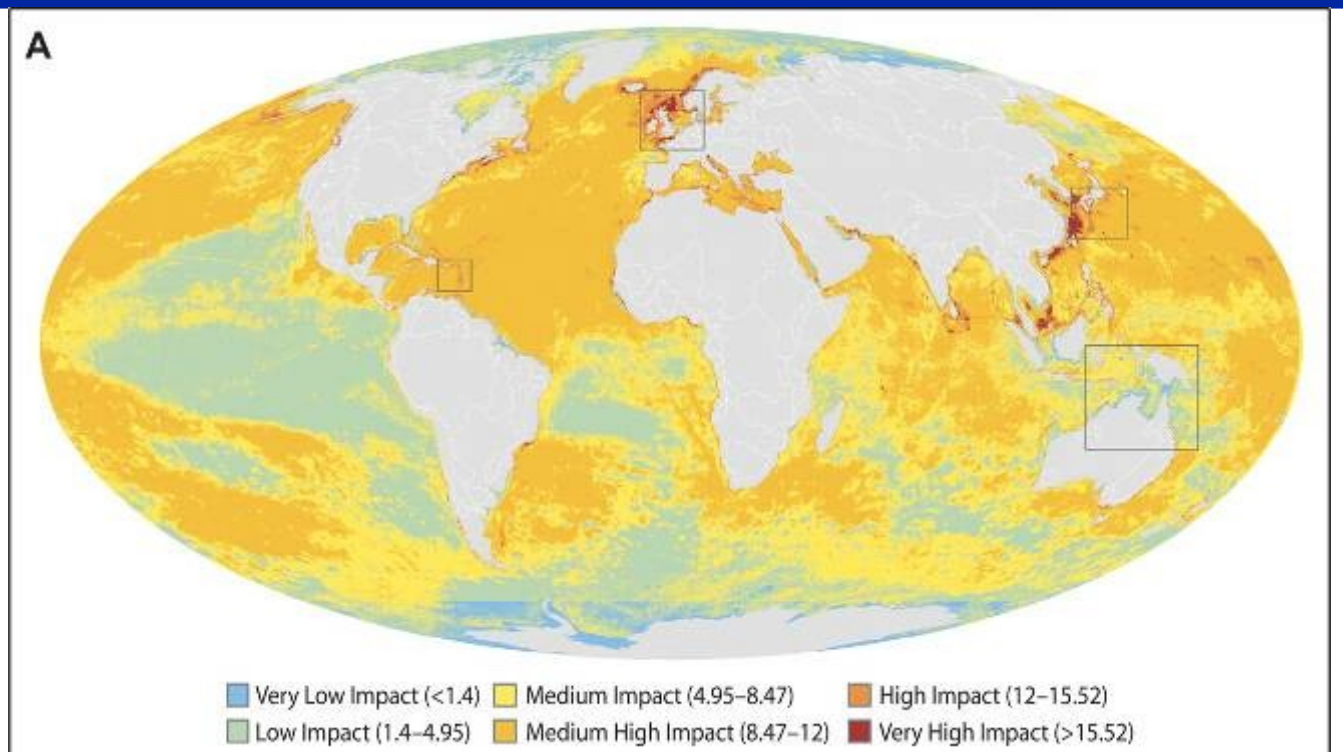
UW's Research Channel Michael Wellings

it2

International Threats to Coral Reefs and Ocean Biology -- Urgent Need for SensorNets



Science December 14, 2007



A Global Map of Human Impact on Marine Ecosystems
Science February 15, 2008



Science May 14, 2007

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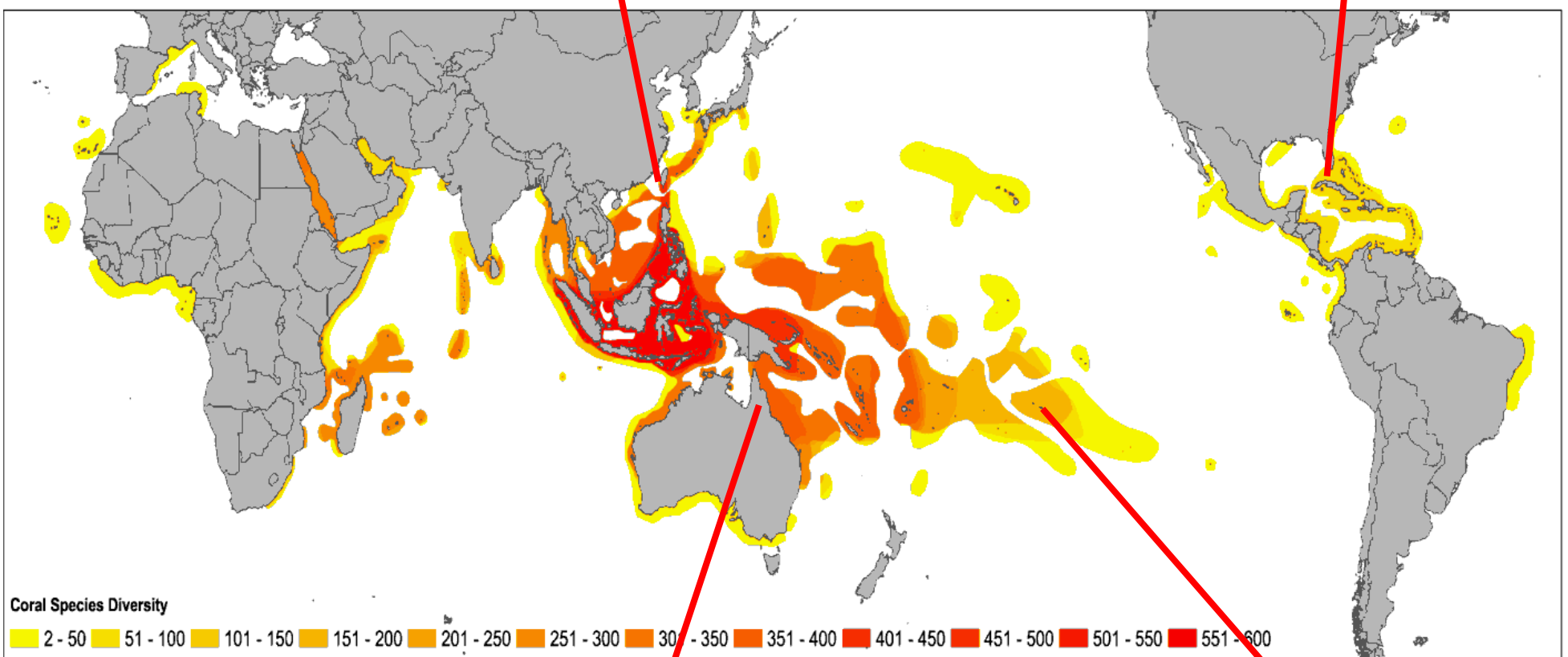
it²

Coral Reef Environmental Observatory Network (CREON)

www.coralreefeon.org/

Taiwan

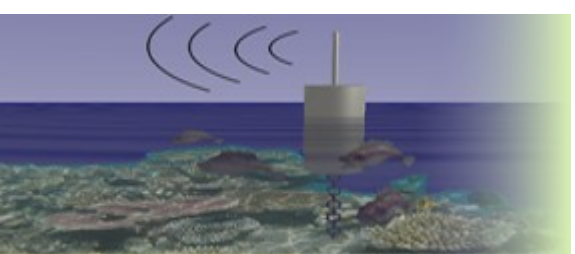
NOAA



NSF Collaboration:
UCSB and AS/NMMBA

GBR

UCSB



Source: Stuart Kininmonth, AIMS

Source : Fang-Pang Lin, NCHC

Taiwan's Kenting's Underwater Observatory

- **Deployed off Southern Taiwan 2004**
  - **Features 10 Underwater Cameras**
    - **Setup To Monitor Different Habitats on The Coral Reef**
  - **Currently Used by Taiwan's Academia Sinica and NMMBA**
- **On-Shore Video Servers are Used to Convert Analog Signals to Digital MJPEG Video Streams**
  - **Remote Observatory, Low Bandwidth (~1 Mbps)**
  - **Video Resolution: 320x240 Pixels**
  - **Effective Transfer Rate: 1 Frame/sec**

OPEN SOURCE DATA TURBINE INITIATIVE
Empowering the Scientific Community with Streaming Data Middleware



CREON



UCSD
UCIrvine

Source: Ebbe Strandell, NCHC

it²

New Year's Challenge: Streaming Underwater Video From Taiwan's Kenting Reef to Calit2's OptIPortal

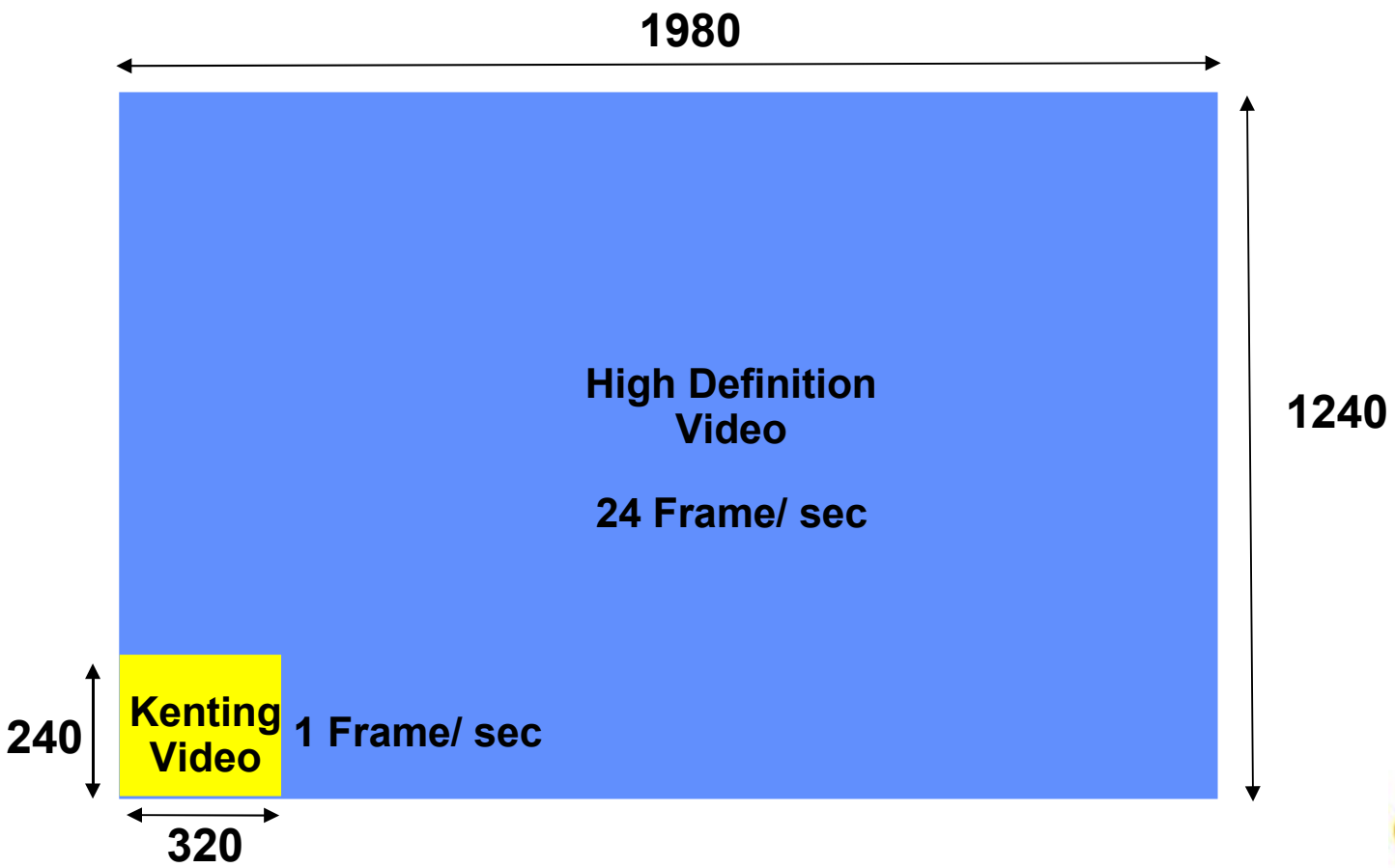


Empowering the Scientific Community with Streaming Data Middleware

UCSD: Rajvikram Singh, Sameer Tilak, Jurgen Schulze, Tony Fountain, Peter Arzberger
NCHC : Ebbe Strandell, Sun-In Lin, Yao-Tsung Wang, Fang-Pang Lin

The Kenting "Bandwidth Bottleneck"

- Currently Limited Bandwidth Access to Underwater Cameras
  - Two ADSL Cables
- Bandwidth Less Than a Megabit/ Sec
  - Severely Limits Video Resolution and Frame Rate
- Kenting Would Benefit From Much Higher Bandwidth



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UCSB Ecological Research Programs: CREON Partner to Kenting Coral Reef

Santa Barbara Channel Long Term Ecological Research (SBC LTER) Program



- Goals
  - Focuses on understanding the nearshore ecosystems of the west coast
  - Time/space variation of individual organisms, populations, and ecological communities

Moorea Long Term Ecological Research (Moorea LTER) Program



- Goals
  - Understanding processing in coral reef, lagoons and forereef
  - Nature of animal and plant community structure and diversity
  - Responses to environmental change induced either by human activities or natural cycles

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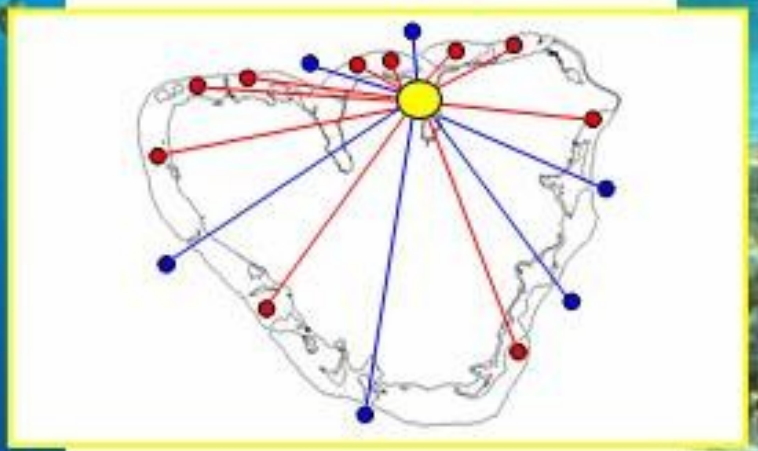
Source: Russell Schmitt, Sally Holbrook, UCSB

Moorea Coral Reef LTER Site
Current Bandwidth ~ 128kbps, But Fiber Optic Cable by 2010

- L
- 2
- P
  U



MCR LTER Sensors







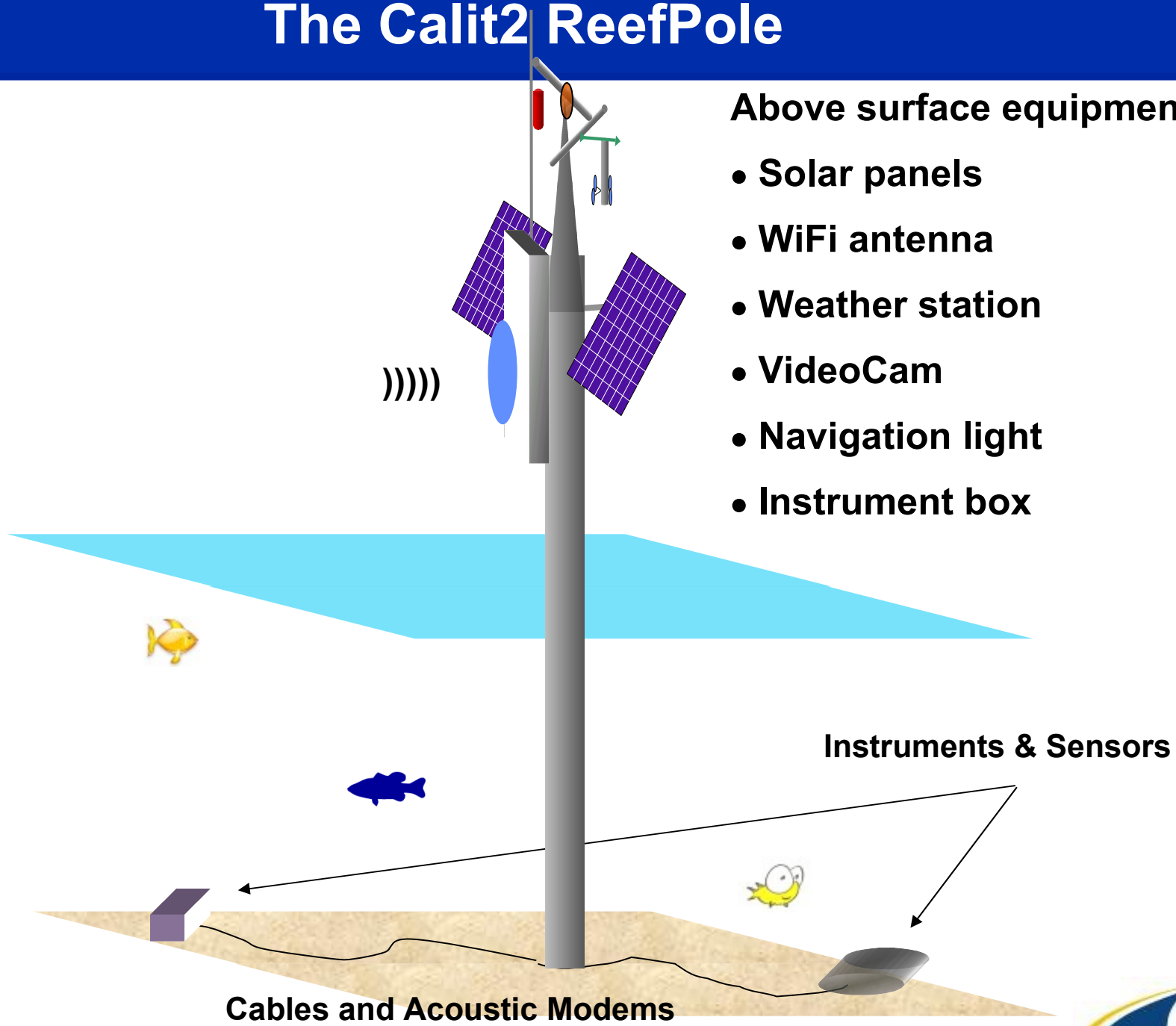








From Flipper Net to High Speed Wireless: The Calit2 ReefPole



Above surface equipment:

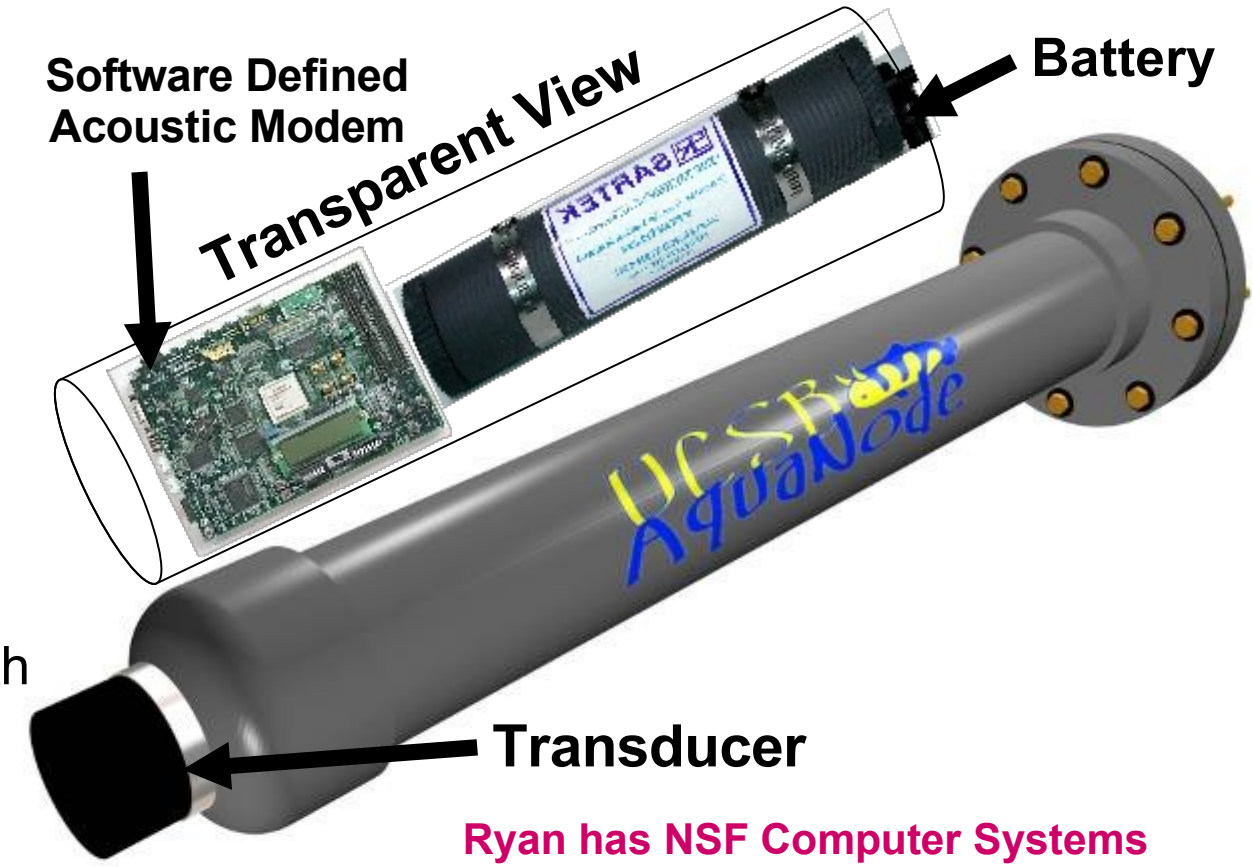
- Solar panels
- WiFi antenna
- Weather station
- VideoCam
- Navigation light
- Instrument box

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AquaNode: Proposed Software Defined Acoustic Modem

- Deploy Ad Hoc Wireless Underwater Networks Around Coral Reef
- Transmit Data Between ReefPole and Underwater Sensors
- Aquanode Requirements:
  - Low Cost, Low Power Wireless Modems
  - Associated Networking Functionality
  - Plug and Play Interface with Variety of Sensors
  - Near Real-time Data and Adaptive Sampling

Under Development at UCSD/UCSB



Ryan has NSF Computer Systems Research Grant to Develop a Software Defined Acoustic Modem (SDAM)

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Source: Ronald Iltis, Hua Lee, Grace Chang, UCSB
Ryan Kastner, Douglas Palmer, UCSD

it²

Calit2 ReefBot Design for Digital Reef Mapping

Explore Every Square Meter of the Moorea Coral Reef from a Remote Desktop







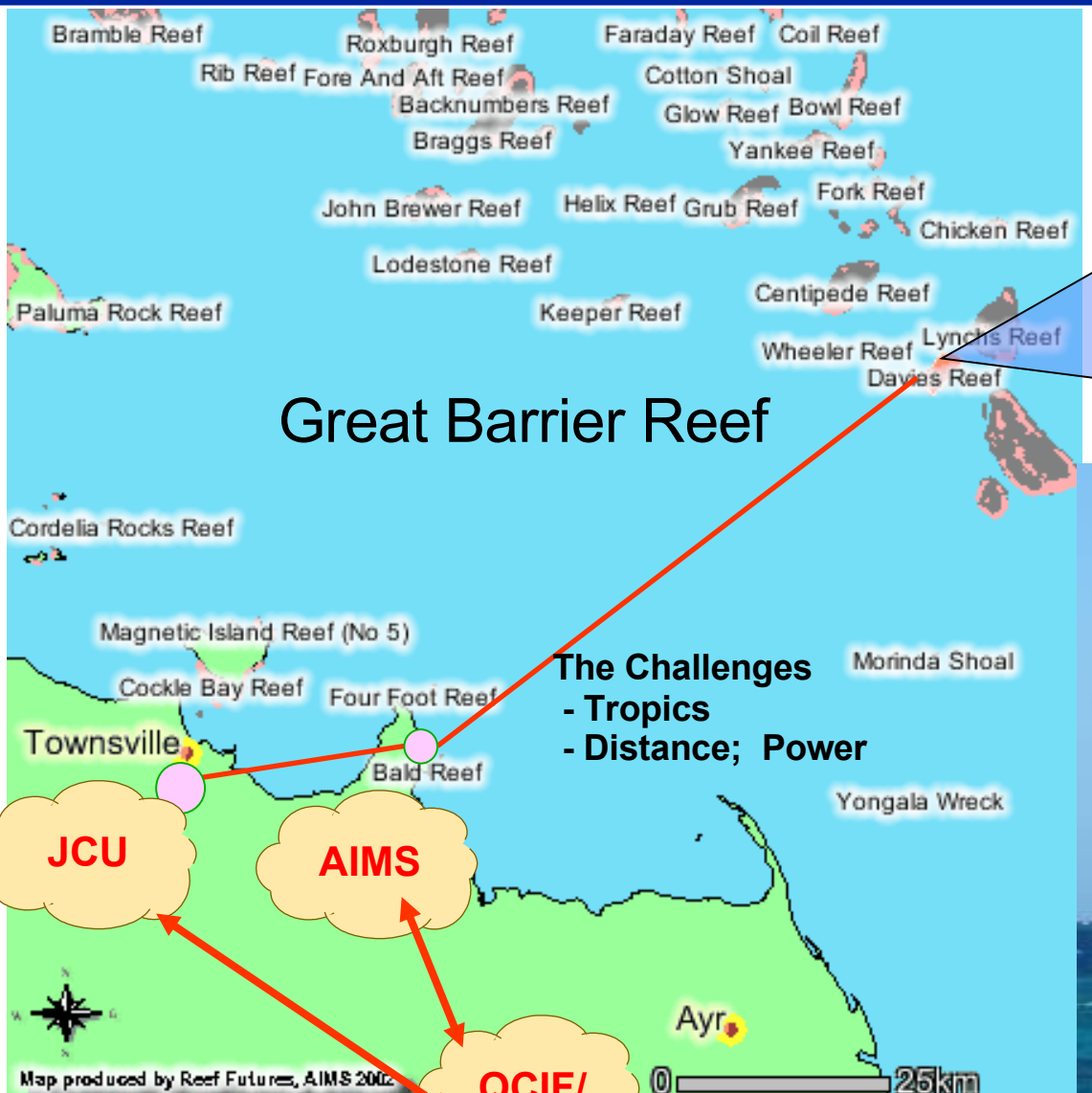
Use The Reef GIS
to Zoom Into
Any Portion
of the Shallow Reef
to View Details Down
to ~ Centimeter

ReefBot Is a Mobile Networked Sensor platform

- **Potential Reef Sensor Suite**
  - Water sampling
  - Computed currents
  - Temperature, turbidity
  - Digital photographic mapping
  - Wave/surf conditions
  - Accurate bathymetry
  - Acoustic monitoring
- **Collected data can be used for multiple studies**
  - Population studies (fish, corals etc)
  - Bleaching, crown of thorns monitoring
  - Growth/destruction profiling
  - Post event assessment
  - Profiling for current/turbidity/siltatation

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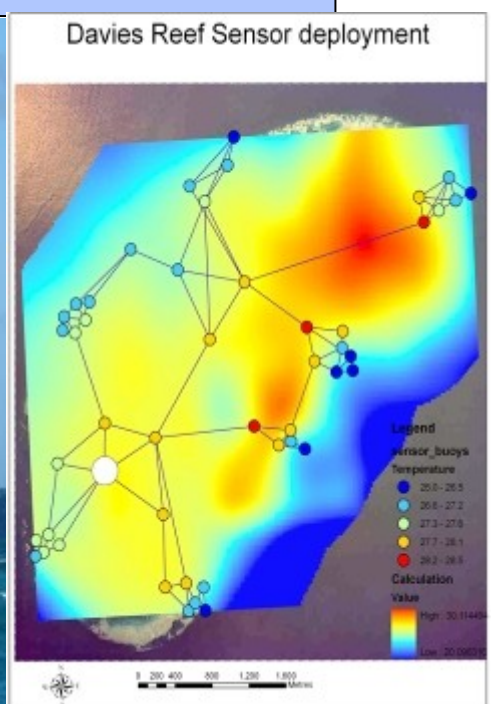
Realtime Sensornets on the Davis Reef Australia With High Speed Wireless Link to Shore



The Challenges
- **Tropics**
- **Distance; Power**







~20Mbps on 10.5 GHz Carrier
~ 70km over Water

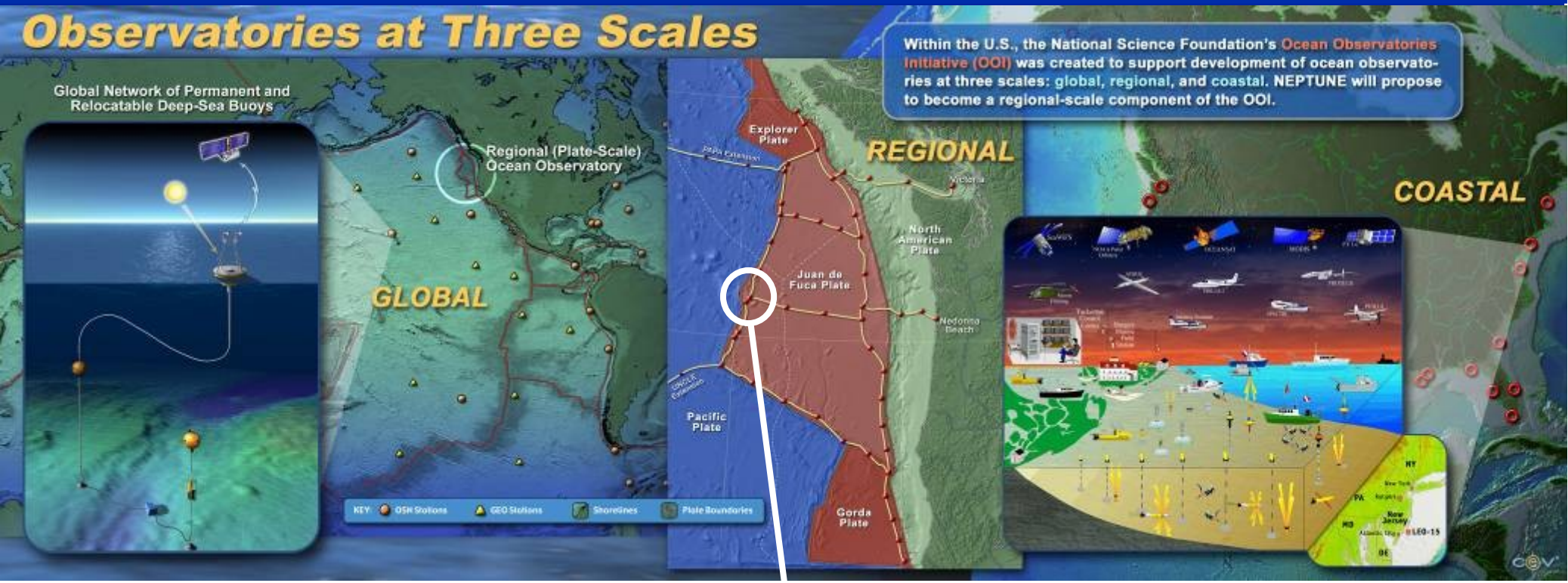
CREON

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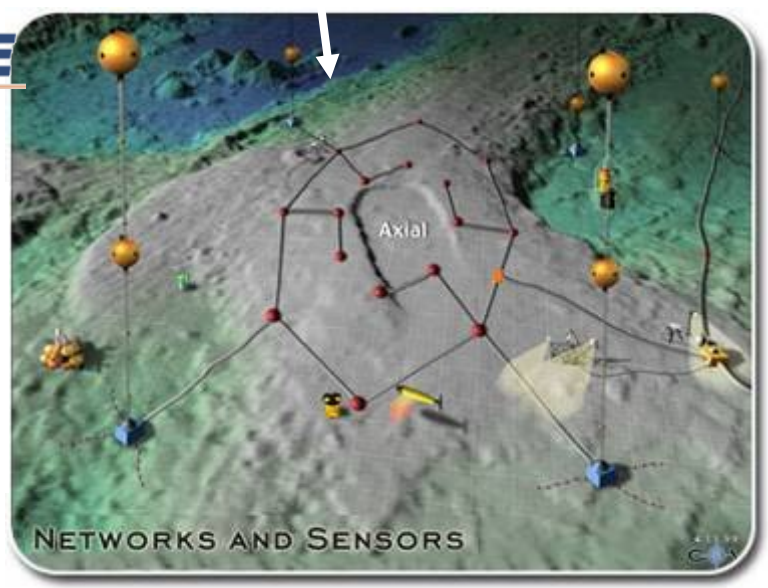
Source: Stuart Kininmonth, Scott Bainbridge, AIMS Australia.

it2

NSF's Ocean Observatories Initiative (OOI) Envisions Global, Regional, and Coastal Scales



NEPTUNE



LEO15 Inset Courtesy of Rutgers University, Institute of Marine and Coastal Sciences

NSF

ocean research interactive ORION observatory networks

UCSD

UCIrvine

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Role of Cyberinfrastructure in NSF's Ocean Observatories Initiative (OOI)



Source: John Orcutt, Matthew Arrott, SIO/Calit2

OOI CI Team:

- UCSD
  - SIO, Calit2, SDSC
- Rutgers
- WHOI
- Raytheon

JOI Awards, Funded by NSF:

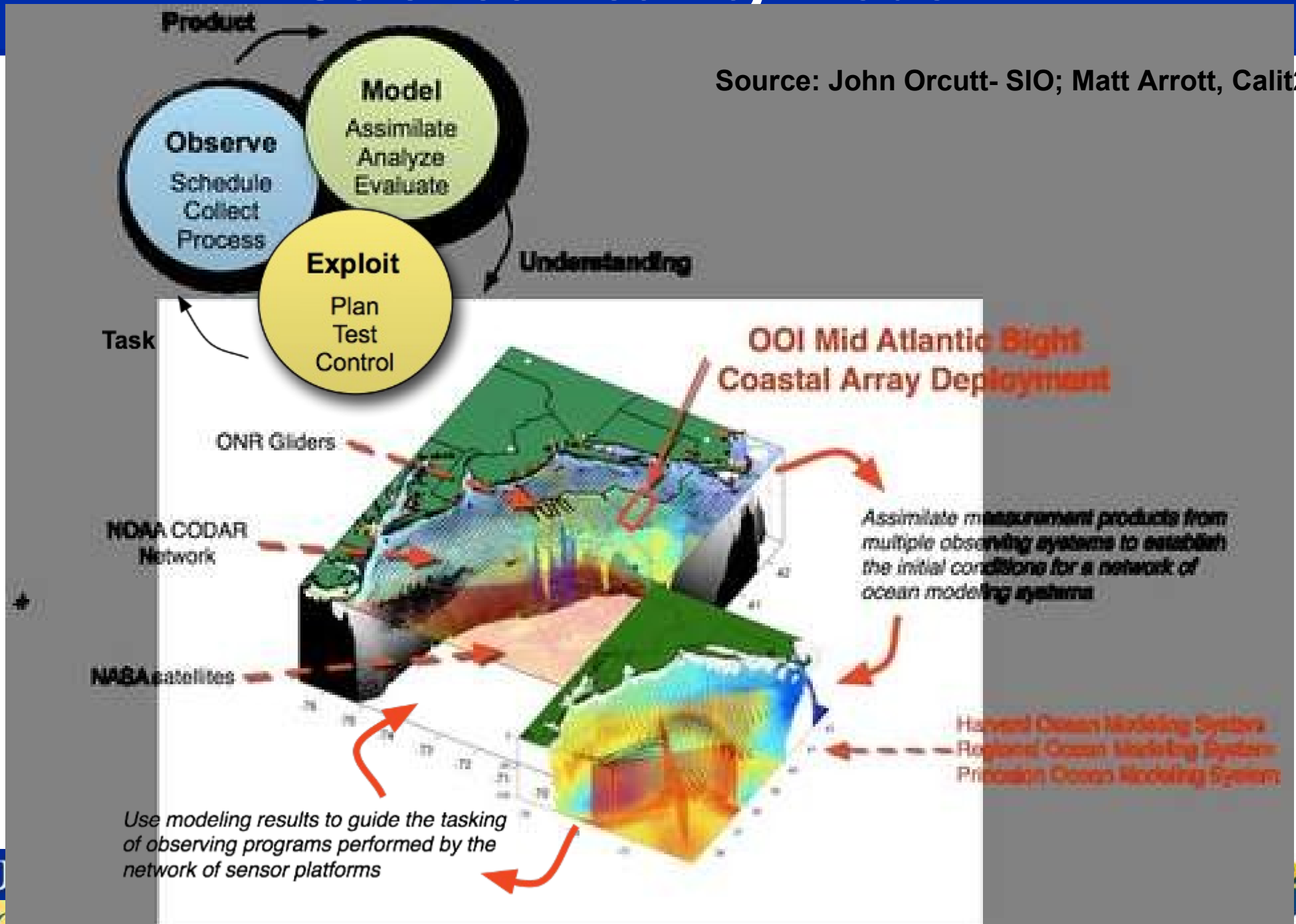
- Node
- sh
- Scale Nodes
  - $120m, Woods Hole Lead
- Cyberinfrastructure
  - $30m, SIO/Calit2 UCSD

Construction Program
5 Year

UCSD
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it²

Science Activity Model



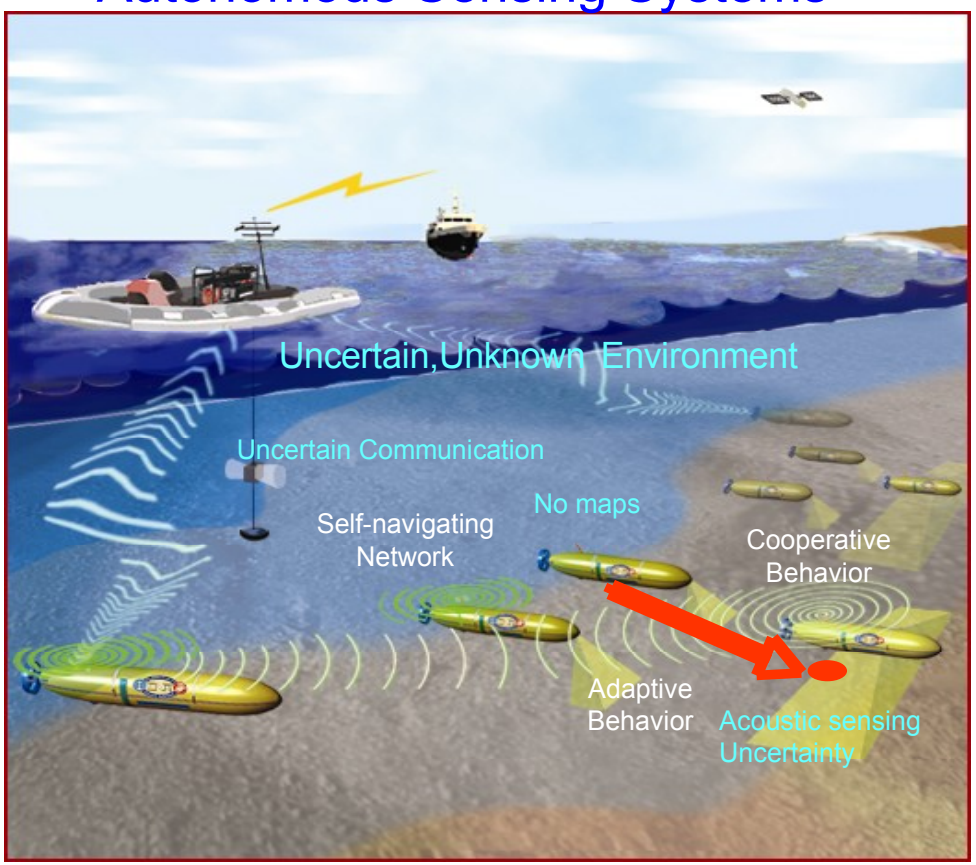
Source: John Orcutt- SIO; Matt Arrott, Calit2

Ocean Sensing Systems – Paradigm Shift

Platform-centric Sensing Systems



Net-centric, Distributed Autonomous Sensing Systems



Similar in Shift to Net-centric Warfighting

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Towards a Total Knowledge Integration System for the Coastal Zone—SensorNets Linked to Fiber Cable

- Moorings
- Ships
- Autonomous Vehicles
- Satellite Remote Sensing
- Drifters
- Long Range HF Radar
- Near-Shore Waves/Currents
- COAMPS Wind Model
- Nested ROMS Models
- Data Assimilation and Modeling
- Data Systems

Atul Nayak
Frank Vernon



Yellow—Proposed Initial OptIPuter Backbone

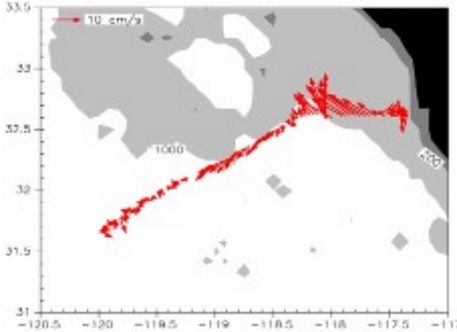
SOUTHERN CALIFORNIA COASTAL OCEAN OBSERVING SYSTEM

ROADNet

UCSD
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www.sccoos.org/

COCMP
Coastal Ocean Currents Monitoring Program





it²