“The Pacific Research Platform Enables Distributed Big-Data Machine-Learning”

Keynote:

Big Data & Extreme-Scale Computing2 (BDEC2)

San Diego, CA

October 15, 2019

Dr. Larry Smarr

Director, California Institute for Telecommunications and Information Technology

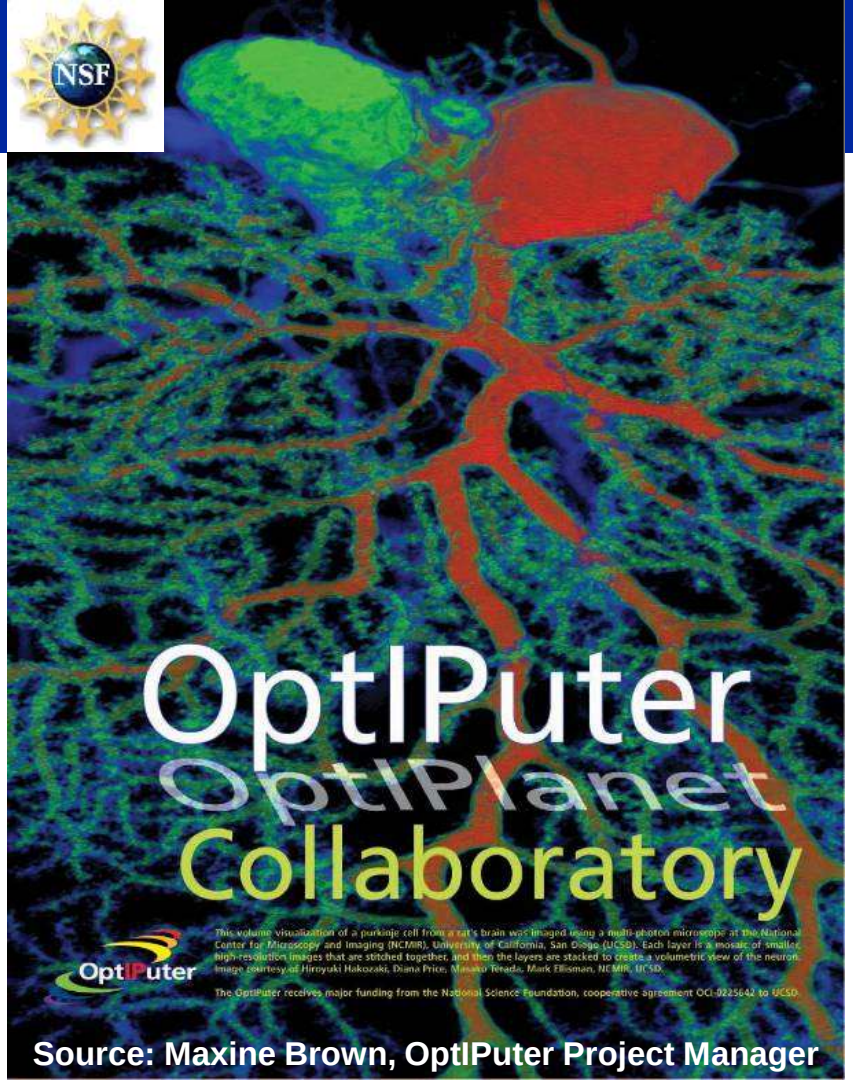
Harry E. Gruber Professor,

Dept. of Computer Science and Engineering

Jacobs School of Engineering, UCSD

http://lsmarr.calit2.net

PACIFIC RESEARCH PLATFORM



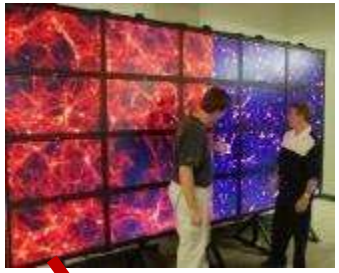
Source: Maxine Brown, OptIPuter Project Manager

The OptIPuter
Exploits a New World
in Which
the Central Architectural Element
is Optical Networking,
Not Computers.

Distributed Cyberinfrastructure
to Support
Data-Intensive Scientific Research
and Collaboration

PI Smarr,
2002-2009

Integrated "OptIPlatform" Cyberinfrastructure System: A 10Gbps Prototype of an NRP



End User OptIPortal



Instruments





HD/4k Video Cams

HPC



Campus Optical Switch

10G Lightpath



TeraGrid

LS 2009 Slide



Data Repositories & Clusters



HD/4k Video Images

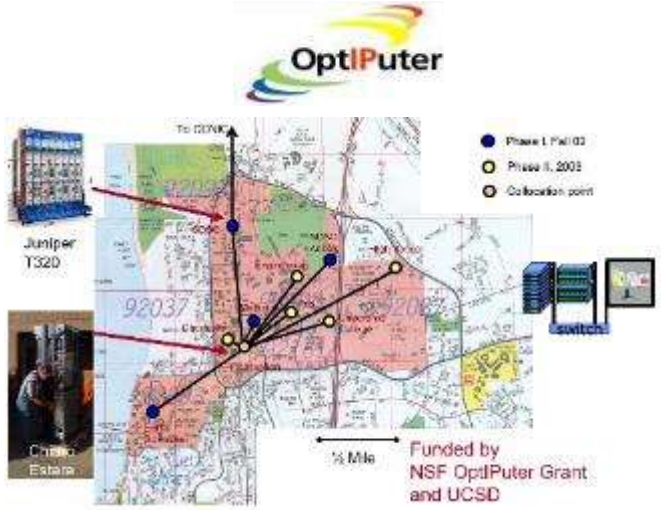
PRP PACIFIC RESEARCH PLATFORM

OptIPuter

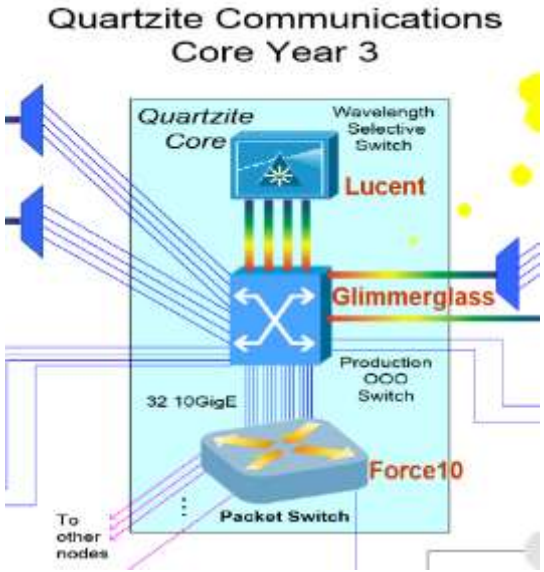
SDSC

it²

2000-2015 Using UCSD Campus as Development Prototype: NSF OptIPuter, Quartzite, Prism Awards

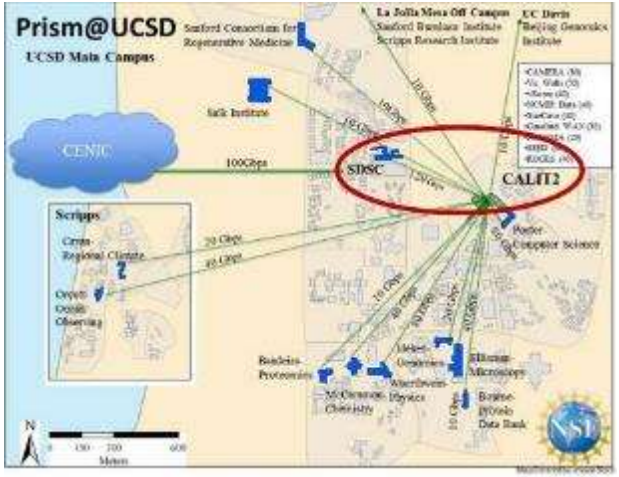


PI Smarr
2002-2009



Goals by 2008:
>= 50 endpoints at 10 GigE
>= 32 Packet switched
>= 32 Switched wavelengths
>= 300 Connected endpoints

PI Papadopoulos
2004-2007



PI Papadopoulos
2013-2015

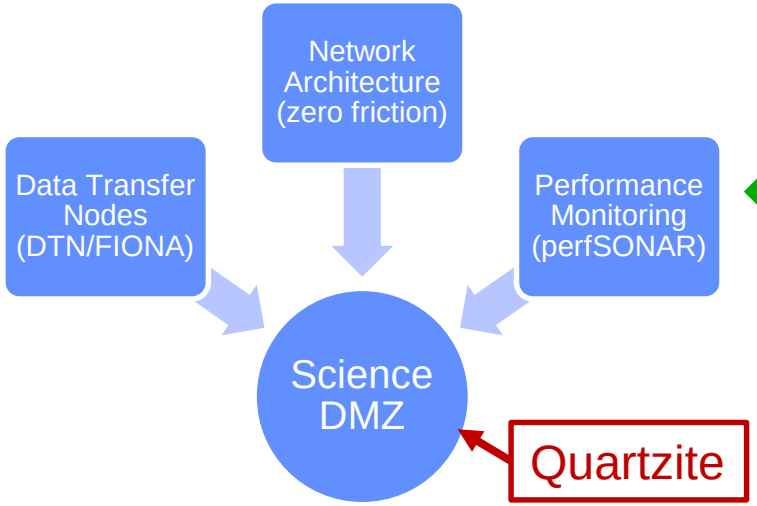
PRP PACIFIC RESEARCH PLATFORM

SDSC

it²

2010-2018: DOE & NSF Partnering on Science Engagement and ScienceDMZ Technology Adoption

ScienceDMZ Coined in 2010 by ESnet
Basis of PRP Architecture and Design



http://fasterdata.es.net/science-dmz/

DOE

NSF

NSF Campus Cyberinfrastructure Program
Has Made Over 250 Awards



Prism

2012 2013 2014 2015 2016 2017 2018

Slide Adapted From Inder Monga, ESnet

PRP PACIFIC RESEARCH PLATFORM

ESnet FASTERDATA KNOWLEDGEBASE

NSF

it²

2015 Vision: The Pacific Research Platform Will Connect Science DMZs Creating a Regional End-to-End Science-Driven Community Cyberinfrastructure



Source: John Hess, CENIC

NSF CC*DNI Grant
$6.3M 10/2015-10/2020
Year 5 Starts in 1 Week!

PI: Larry Smarr, UC San Diego Calit2
Co-PIs:

- **Camille Crittenden, UC Berkeley CITRIS,**
- **Tom DeFanti, UC San Diego Calit2/QI,**
- **Philip Papadopoulos, UCI**
- **Frank Wuerthwein, UCSD Physics and SDSC**

Letters of Commitment from:

- ***50 Researchers from 15 Campuses***
- ***32 IT/Network Organization Leaders***

ESnet: Given Fast Networks, Need DMZs and Fast/Tuned DTNs

PACIFIC RESEARCH PLATFORM

PRP Engineers Designed and Built Several Generations of Optical-Fiber Big-Data Flash I/O Network Appliances (FIONAs)

UCSD-Designed FIONAs Solved the Disk-to-Disk Data Transfer Problem *at Near Full Speed* on Best-Effort 10G, 40G and 100G Networks



Two FIONA DTNs at UC Santa Cruz: 40G & 100G
Up to 192 TB Rotating Storage





Add Up to 8 Nvidia GPUs Per 2U FIONA
To Add Machine Learning Capability

FIONAs Designed by UCSD's Phil Papadopoulos, John Graham, Joe Keefe, and Tom DeFanti

Installing FIONAs Across California in Late 2018 and Early 2019
To Enhance User's CPU and GPU Computing, Data Posting, and Data Transfers



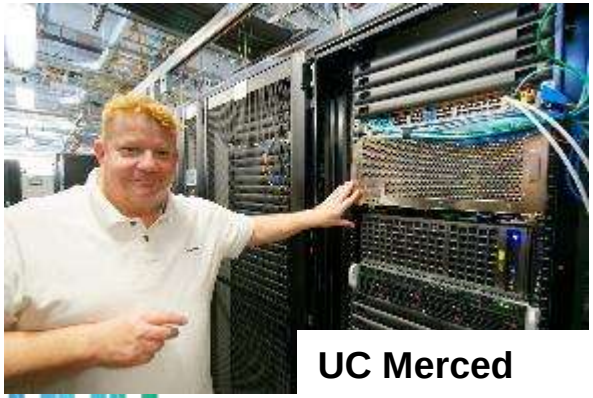
UC Irvine



Stanford



UC Santa Barbara



UC Merced



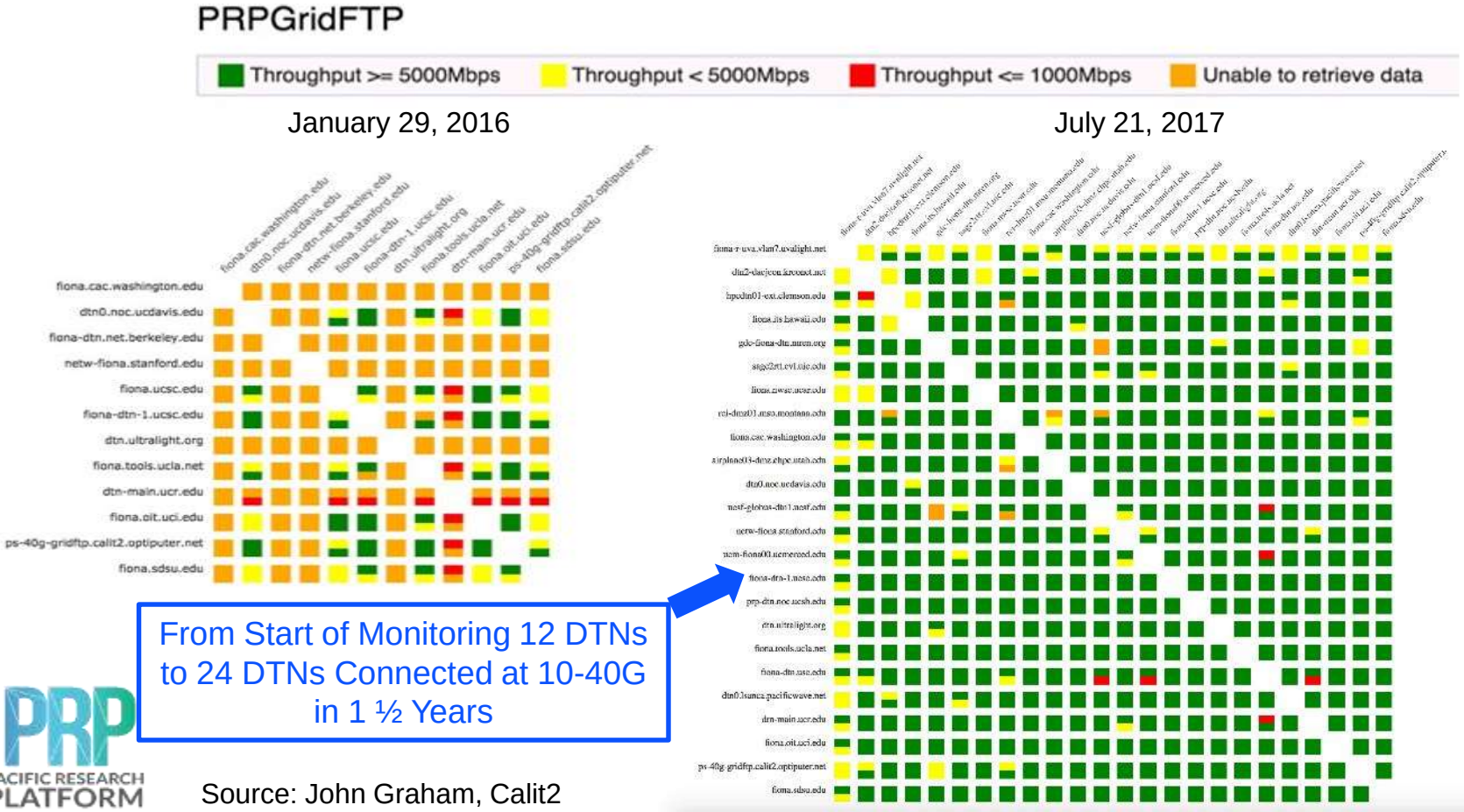
UC Santa Cruz



UC Riverside

PACIFIC RESEARCH PLATFORM

We Measure Disk-to-Disk Throughput with 10GB File Transfer 4 Times Per Day in Both Directions for All PRP Sites



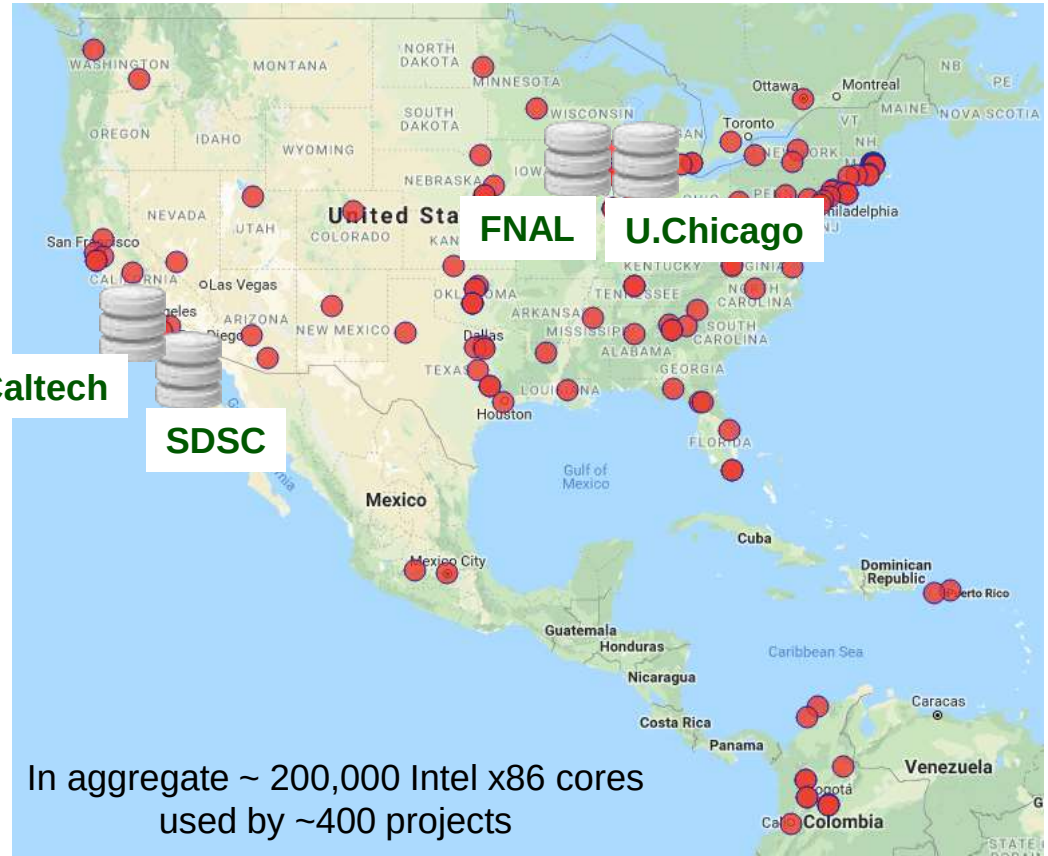
From Start of Monitoring 12 DTNs to 24 DTNs Connected at 10-40G in 1 ½ Years

Source: John Graham, Calit2

OSG (an NRP Providing High Throughput Compute & Data Resources) Has Been Integrated With the PRP

OSG Federates ~100 Clusters Worldwide

Source: Frank Würthwein, OSG Exec Director; PRP co-PI UCSD/SDSC



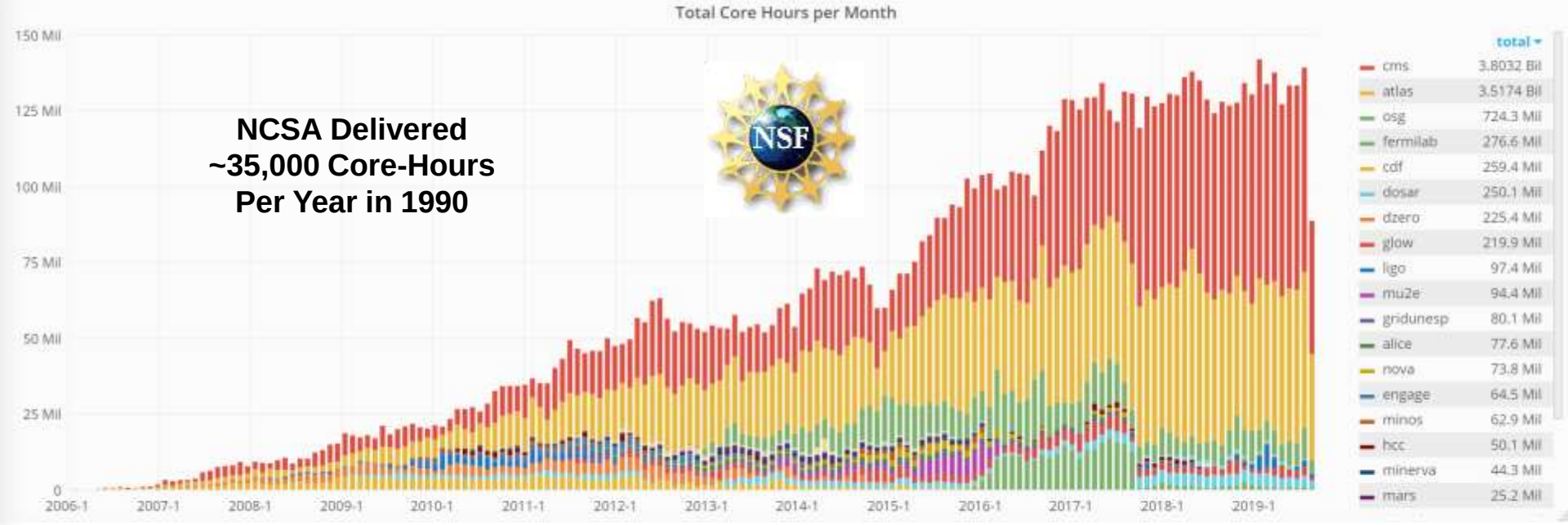
Open Science Grid

PRP PACIFIC RESEARCH PLATFORM

NSF

it²

The Open Science Grid Delivers
1.8 Billion Core-Hours Per Year to Over 50 Fields of Science



NCSA Delivered ~35,000 Core-Hours Per Year in 1990

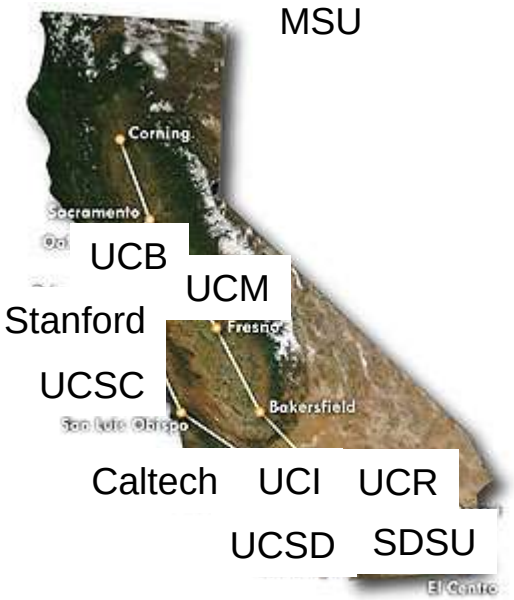
Active Virtual Organizations	Active Sites	Represented Fields of Science
20	149	50

PRP PACIFIC RESEARCH PLATFORM

GRACC Grid Accounting

https://gracc.opensciencegrid.org/dashboard/db/gracc-home

2017-2020: NSF CHASE-CI Grant Adds a Machine Learning Layer Built on Top of the Pacific Research Platform



CI-New: Cognitive Hardware and Software Ecosystem Community Infrastructure (CHASE-CI)

For the Period September 1, 2017 – August 31, 2020

SUBMITTED – January 18, 2017

PI: Larry Smarr, Professor of Computer Science and Engineering, Director Calit2, UCSD
Co-PI: Tajana Rosing, Professor of Computer Science and Engineering, UCSD
Co-PI: Ken Kreutz-Delgado, Professor of Electrical and Computer Engineering, UCSD
Co-PI: Ilkay Altintas, Chief Data Science Officer, San Diego Supercomputer Center, UCSD
Co-PI: Tom DeFanti, Research Scientist, Calit2, UCSD

NSF Grant for High Speed "Cloud" of 256 GPUs
For 30 ML Faculty & Their Students at 10 Campuses
for Training AI Algorithms on Big Data

PRP PACIFIC RESEARCH PLATFORM

JACOBS SCHOOL OF ENGINEERING

SDSC UC San Diego it²

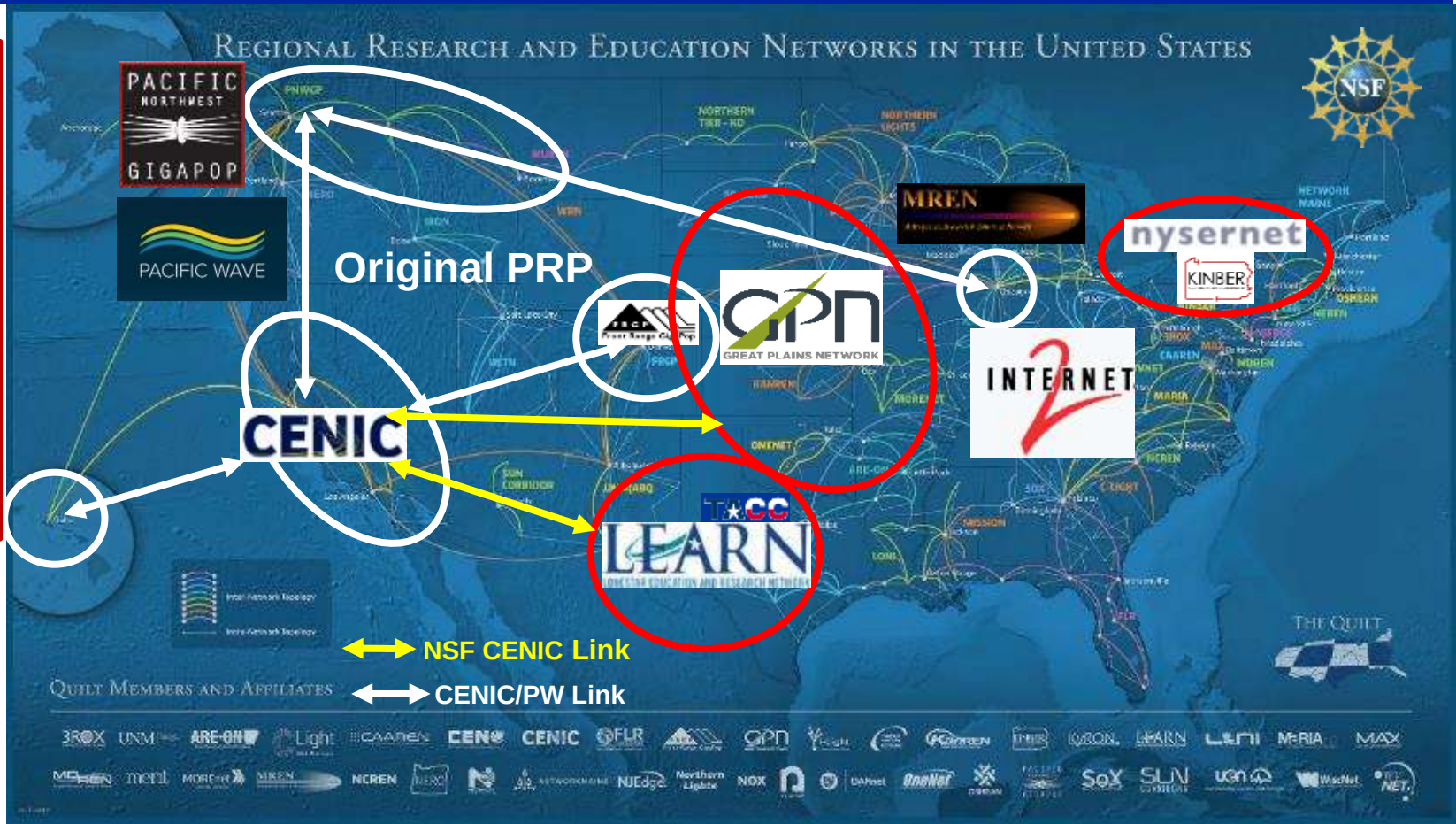
2018-2021: Toward the NRP - Using CENIC & Internet2 to Connect Quilt Regional R&E Networks

"Towards The NRP"
3-Year Grant Funded by NSF
$2.5M
October 2018

PI Smarr
Co-PIs Altintas
Papadopoulos
Wuerthwein
Rosing
DeFanti

SDSC

PRP
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2018/2019: PRP Game Changer!
Using Kubernetes to Orchestrate Containers Across the PRP

CADE METZ BUSINESS 06.10.14 01:15 PM

GOOGLE OPEN SOURCES ITS SECRET WEAPON IN CLOUD COMPUTING

WIRED

"Kubernetes is a way of stitching together a collection of machines into, basically, a big computer,"
--Craig Mcluckie, Google
and now CEO and Founder of Heptio

"Everything at Google runs in a container."
--Joe Beda,Google

How Kubernetes Conquered 2017 (and is Positioned for 2018)





Dan Meyer
December 25, 2017

sdx central

Kubernetes, an open-source software project that started at Google, has exploded in popularity and is now used by at least 54% of the Fortune 500. BUSINESS INSIDER **Rosalie Chan** Jan. 27, 2019,

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CLOUD NATIVE COMPUTING FOUNDATION

it²

PRP Uses Cloud-Native Rook as a Storage Orchestrator, Running 'Inside' Kubernetes



Battle-tested, production storage

Rook is based on an embedded version of Ceph, which has 10+ years of production deployments and runs some of the worlds largest clusters.

Cloud-native environment integration

Rook runs as a cloud-native service for optimal integration with applications in need of block, object, or file storage.

PRP PACIFIC RESEARCH PLATFORM

Source: John Graham, Calit2/QI

it²

PRP's Nautilus Hypercluster Adopted Kubernetes to Orchestrate Software Containers and Manage Distributed Storage

Nautilus

kubernetes

Kubernetes (K8s) is an open-source system for automating deployment, scaling, and management of containerized applications.



Planet Scale

Designed on the same principles that allows Google to run billions of containers a week, Kubernetes can scale without increasing your ops team.

"Kubernetes with Rook/Ceph Allows Us to Manage Petabytes of Distributed Storage and GPUs for Data Science, While We Measure and Monitor Network Use."
--John Graham, Calit2/QI UC San Diego

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Using Kubernetes to Surround the PRP/CHASE-CI Machine Learning Platform With Clouds of CPUs, GPUs and Non-Von Neumann Processors

288
64-bit GPUs



NSF

CHASE-CI



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Field-Programmable Gate Arrays (FPGA)

XILINX

Micron

Amazon Boosts Cloud-Computing Performance With New, GPU-Accelerated AWS Instances

amazon web services

Google Cloud TPU

Microsoft Azure

GPU-ACCELERATED MICROSOFT AZURE

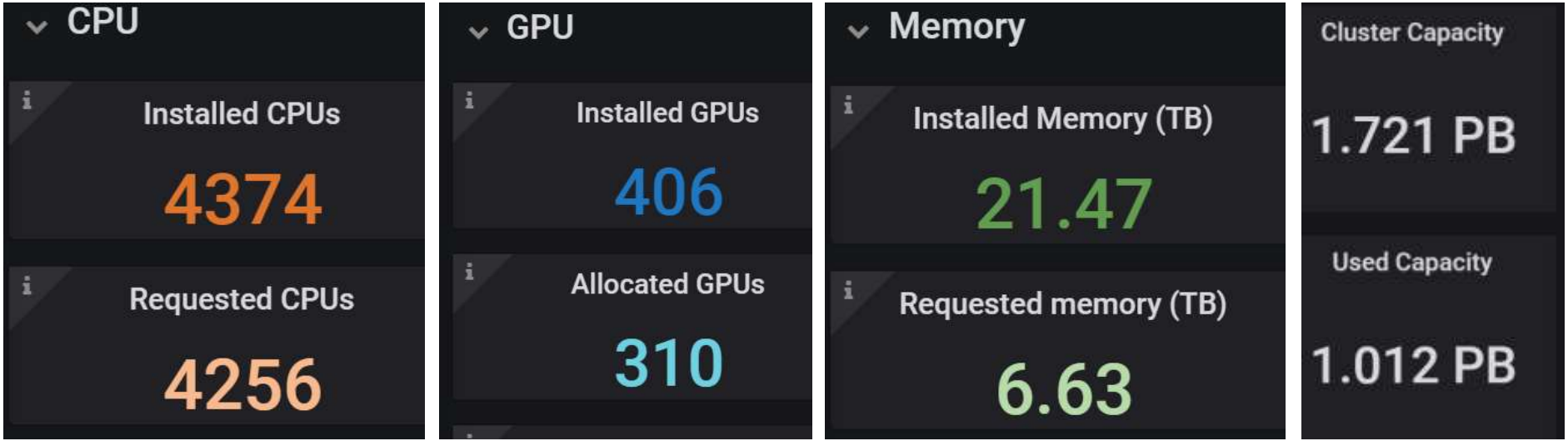
Japan plans to build the fastest deep learning supercomputer

AIST
ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)

4352x NVIDIA Tesla V100 GPUs

it²

PRP's Nautilus Forms a Multi-Application Powerful Distributed "Big Data" Storage and Machine-Learning Computer



Source: grafana.nautilus.optiputer.net on 9/22/2019

PRP's California Nautilus Hypercluster Connected by Use of CENIC 100G Network

Nautilus

Minority Serving Institution

PRP Disks
CHASE-CI
*= July RT

Calit2/UCI
4 FIONA8s*
40G 160TB
40G 160TB HPWREN

UCR
40G 160TB
1 FIONA8

USC
40G 160TB

UCLA
2x40G 160TB
100G NVMe 6.4TB

Caltech
100G NVMe 6.4TB

USD
40G 192TB

CSUSB
10G 3TB

UCSB
40G 192TB
2 FIONA8s*

CENIC

15-Campus Nautilus Cluster:
4360 CPU Cores 134 Hosts
~1.7 PB Storage
407 GPUs, ~4000 cores each

UCSC
40G 160TB
100G NVMe 6.4TB
4.5 FIONA8s

NPS
100G 48TB

SDSC @ UCSD
8 FIONA8s + 5 FIONA8s
100G Gold NVMe
100G Epyc NVMe

UCSD
2x40G 160TB HPWREN
17 FIONA8s
35 FIONA2s

SDSU
FPGAs + 2PB BeeGFS
1 FIONA8* 2 FIONA4s
100G NVMe 6.4TB
40G 160TB HPWREN

UCM
40G 160TB
2 FIONA8
10 FIONA2s

UCSF
40G 192TB

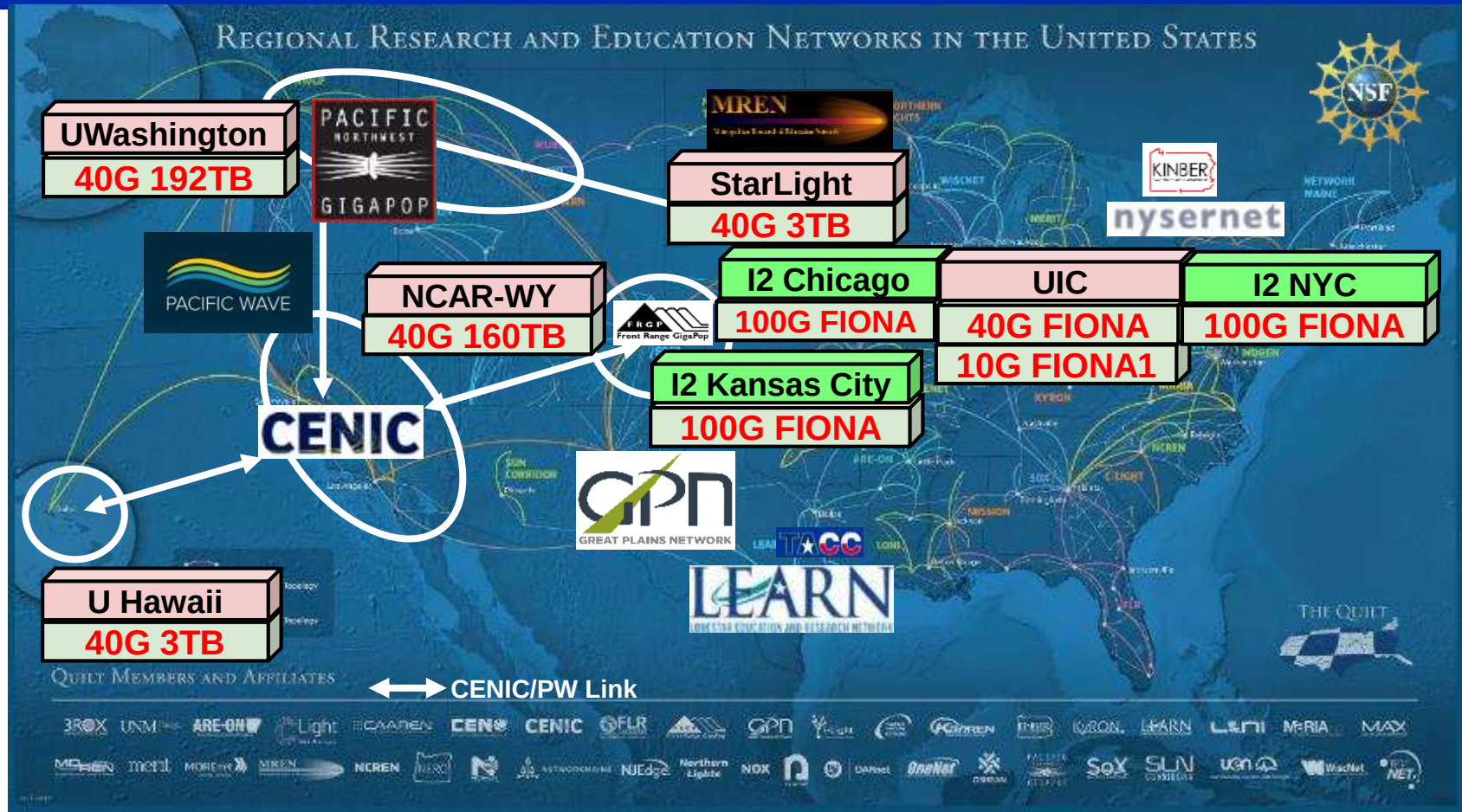
Stanford U
40G 160TB
1 FIONA8*

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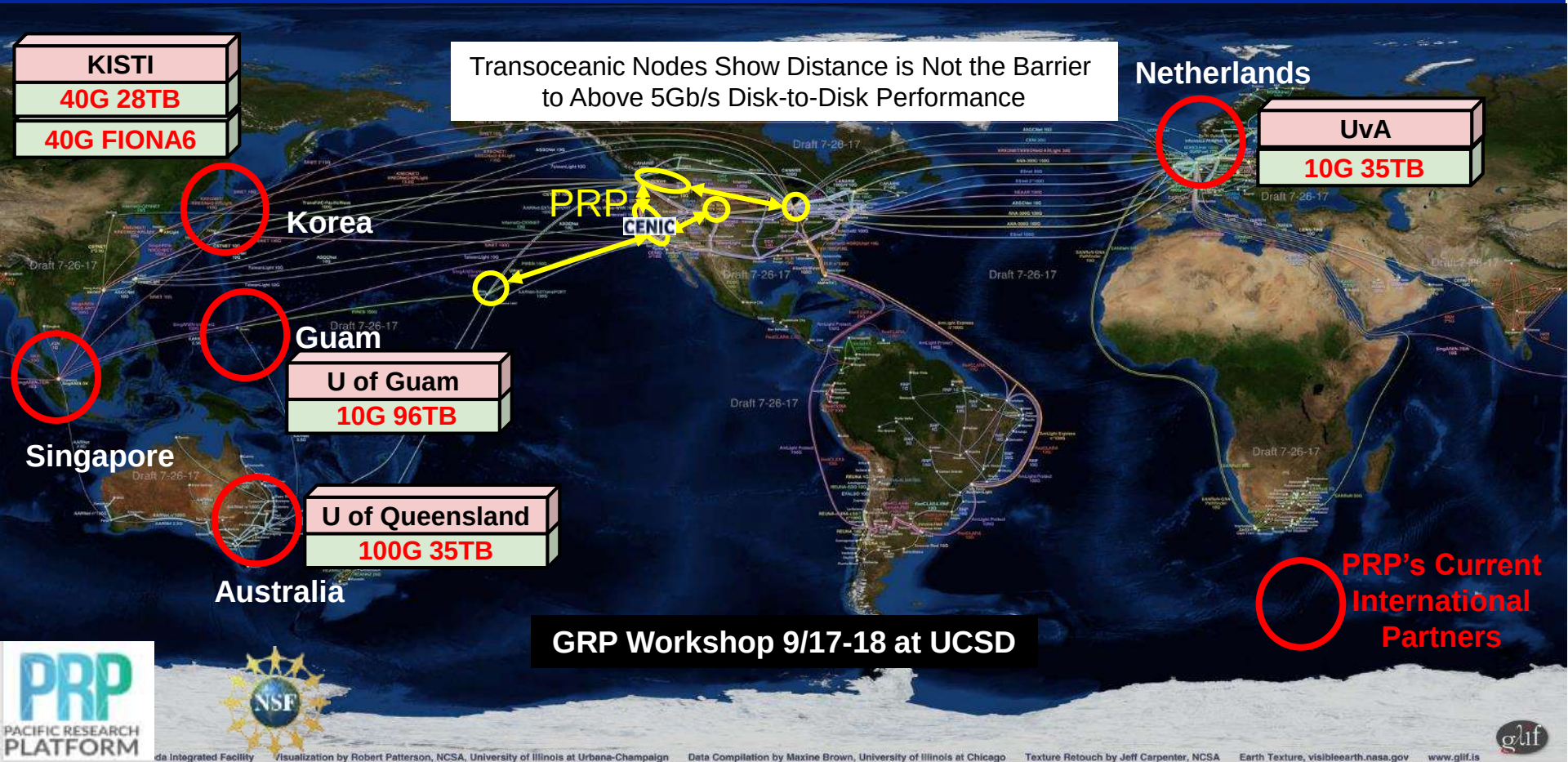
it²

PRP/TNRP's United States Nautilus Hypercluster FIONAs Now Connects 4 More Regionals and 3 Internet2 sites



PACIFIC RESEARCH PLATFORM

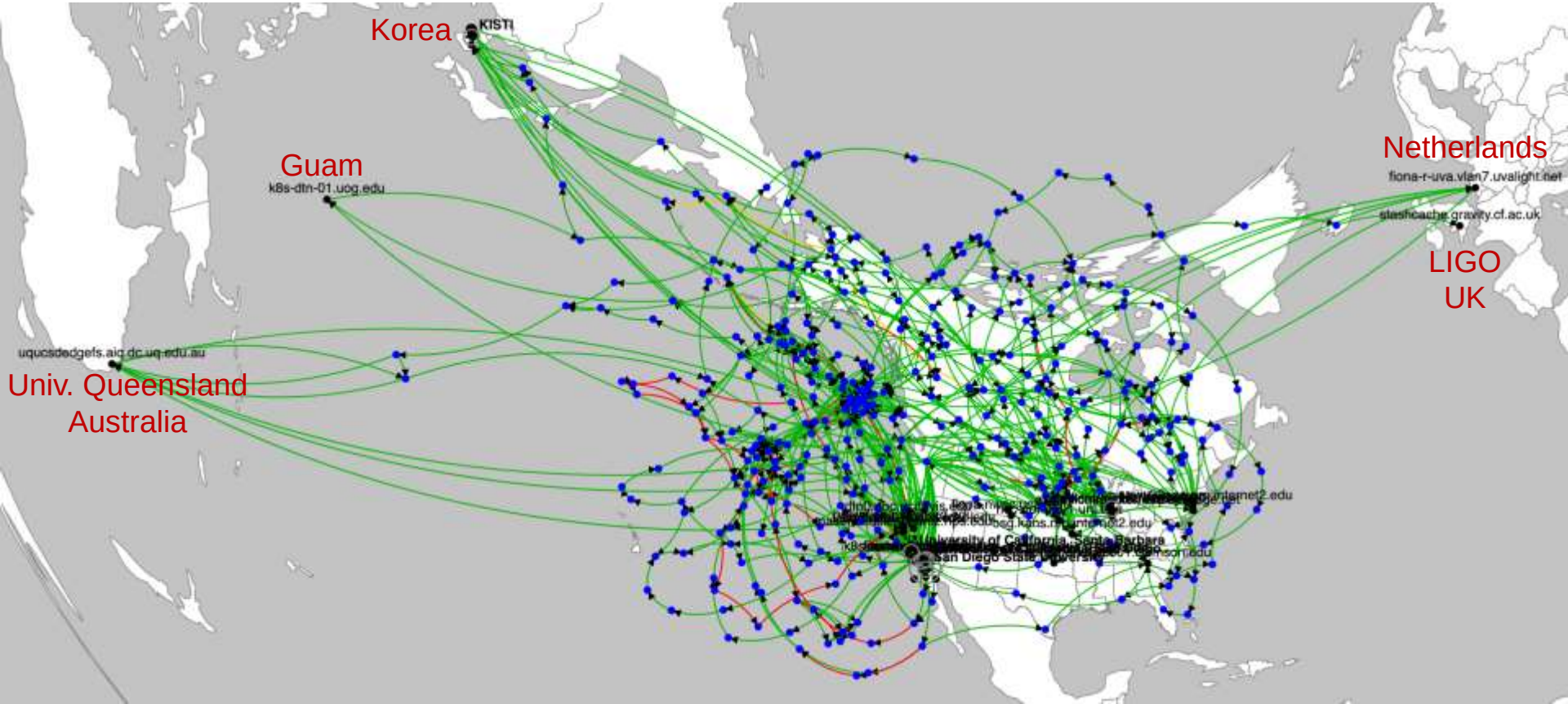
Global PRP Nautilus Hypercluster Is Rapidly Adding International Partners Beyond Our Original Partner in Amsterdam



Operational Metrics: Containerized Trace Route Tool Allows Realtime Visualization of Status of PRP Network Links on a National and Global Scale

9/16/2019

Source: Dima Mishin, SDSC



The First GRP Workshop Was Held One Month Ago



PRP is Science-Driven:
Connecting Multi-Campus Application Teams and Devices



CMS

Particle Physics

Biomedical ‘omics

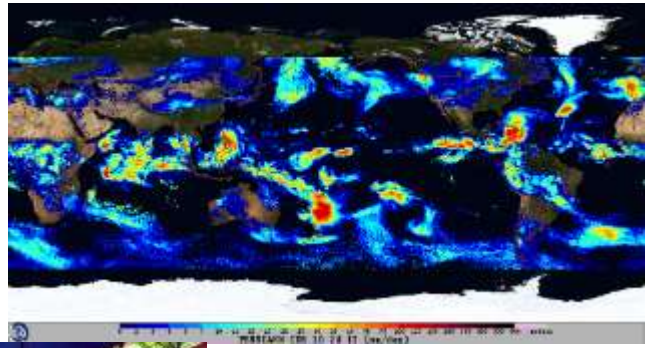


NSF

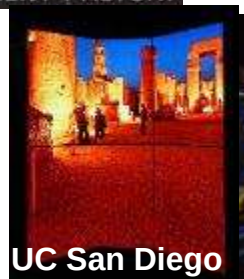


Telescope Surveys

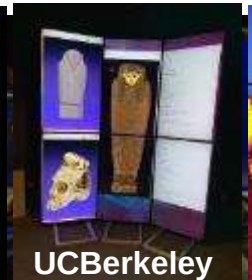
Earth Sciences



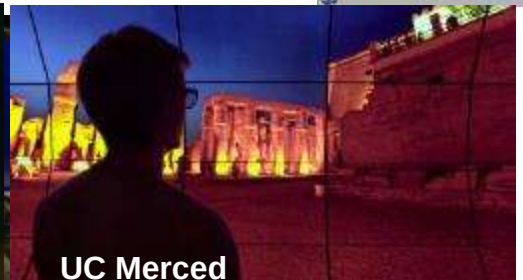
Visualization, Virtual Reality, Collaboration



UC San Diego



UCBerkeley

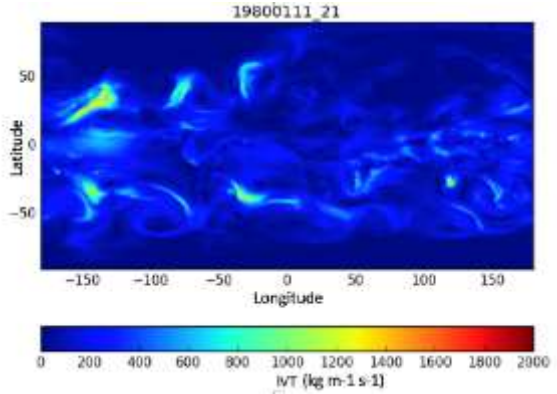


UC Merced

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PRP Enables Speed-Ups of Complex Distributed Workflows: Scott Sellars' Rapid 4D Object Segmentation of NASA Water Vapor Data

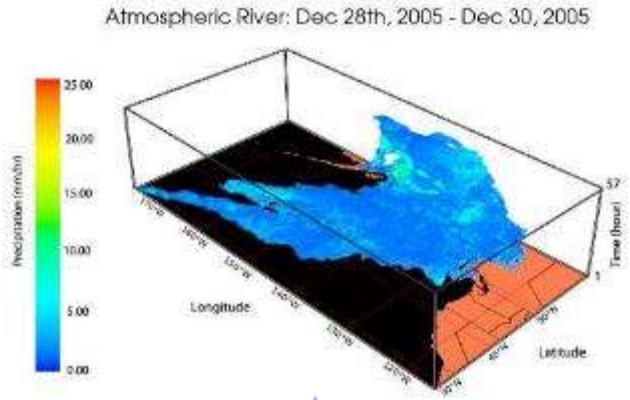
NASA *MERRA v2 – Water Vapor Data Across the Globe



Object Detection, Segmentation and Tracking



4D Object Constructed (Lat, Lon, Value, Time)



Scott L. Sellars[1], John Graham[1], Dima Mishin[1], Kyle Marcus[2] , Ilkay Altintas[2], Tom DeFanti[1], Larry Smarr[1], Joulien Tatar[3], Phu Nguyen[4], Eric Shearer[4], and Soroosh Sorooshian[4]

[1]Calit2@UCSD; [2]SDSC; *[3]Office of Information Technology, UCI; [4]Center for Hydrometeorology and Remote Sensing, UCI*

PRP Enabled Scott's Workflow to Run 532 Times Faster!

Pacific Research Platform (10-100 Gb/s)

Complete workflow time: 19.2 days→52 Minutes!

UC, Irvine

GPUs



Calit2's FIONA

SDSC's COMET



Source: Scott Sellers, CW3E

UC, San Diego

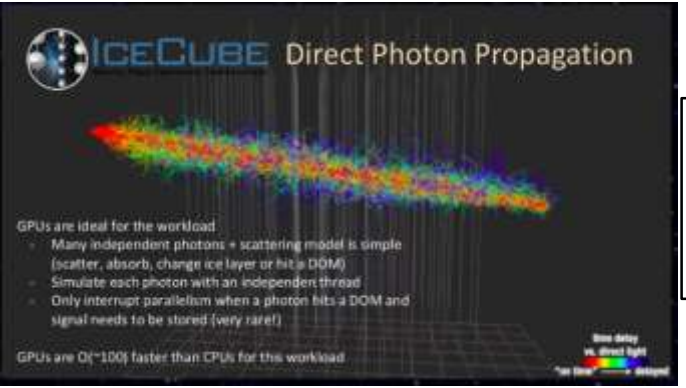
GPUs



Calit2's FIONA

NSF Large-Scale Observatories
Are Beginning to Utilize PRP Compute Resources





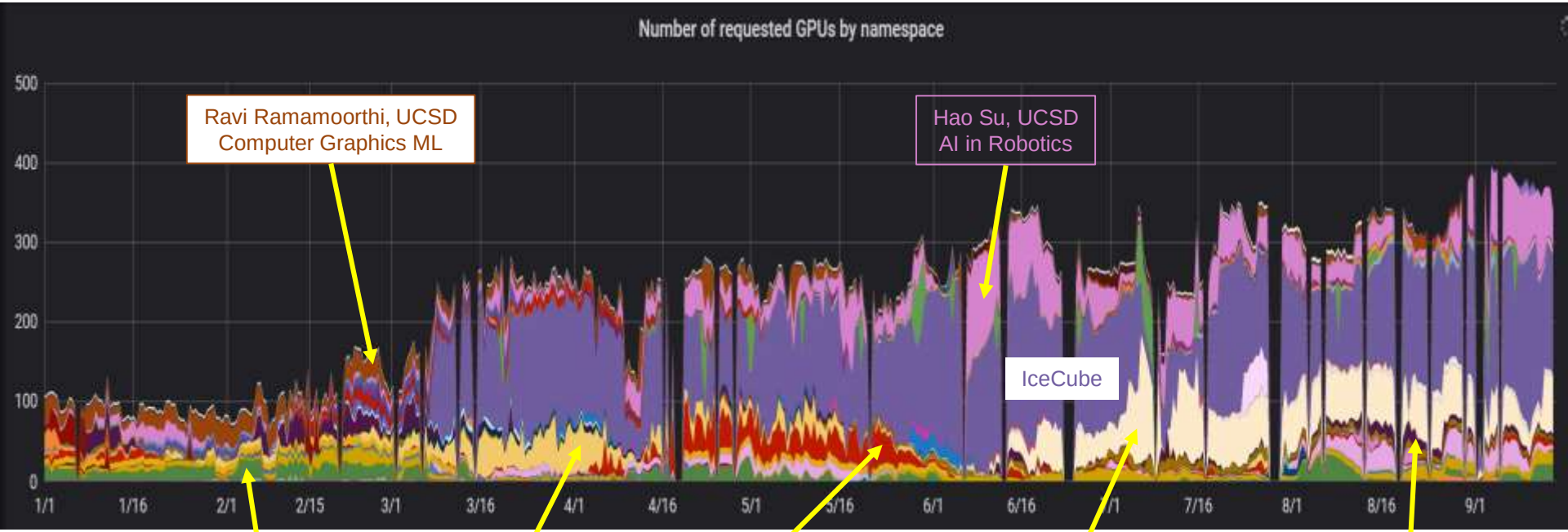
GPU Simulations Needed *to Improve Ice Model*.
=> Results in Significant Improvement in Pointing Resolution for Multi-Messenger Astrophysics

PRP
PACIFIC RESEARCH PLATFORM

IceCube & LIGO Both See Nautilus
as Just Another OSG Resource

it²

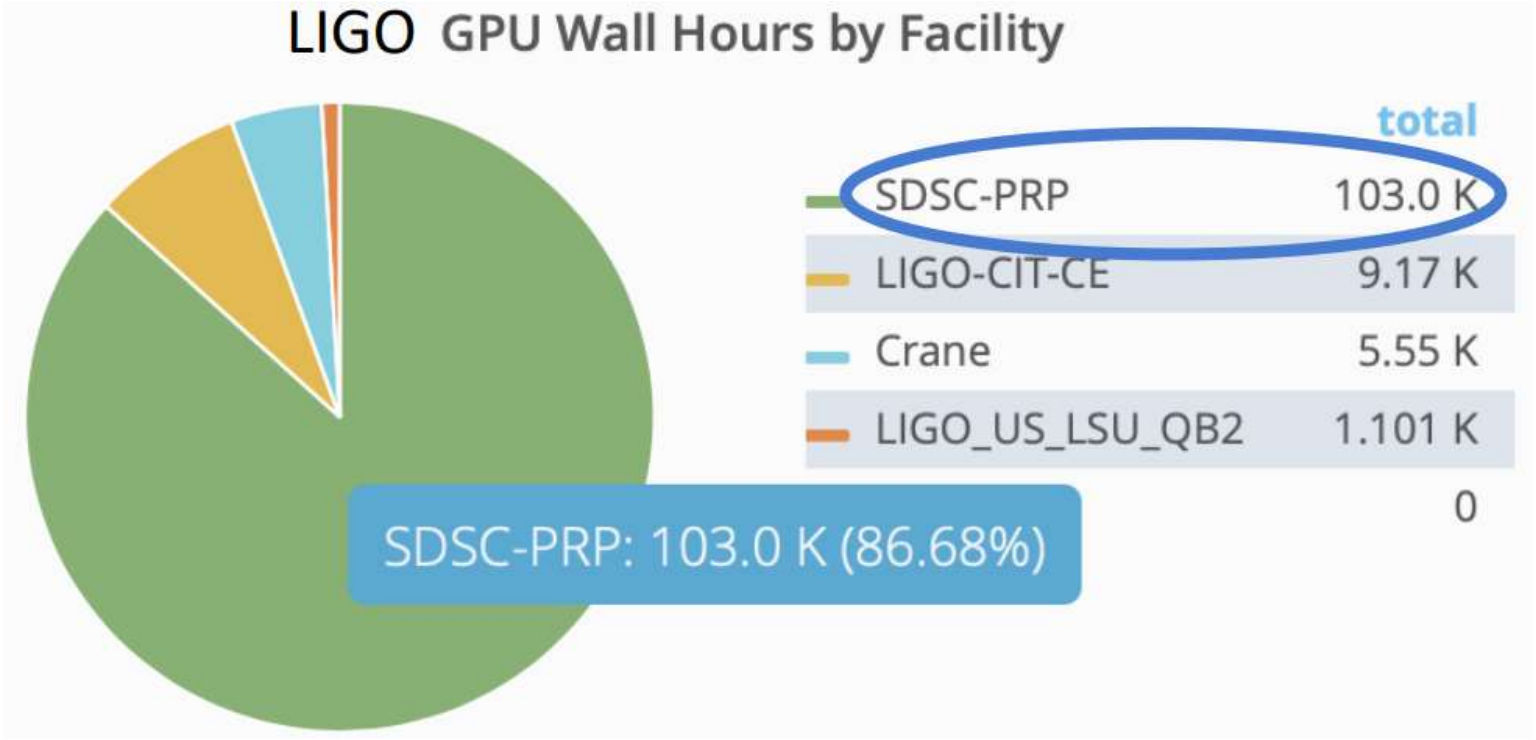
In 2019 a Growing Number of Applications and Campuses Have Driven a 4-Fold Increase in Requested Nautilus GPUs



PACIFIC RESEARCH PLATFORM

https://grafana.nautilus.optiputer.net

Over the Last 3 Months, PRP Nautilus Has Grown to Providing the Great Majority of LIGO GPU Compute Time



Source: GRP Talk by Igor Sfiligoi, UCSD/SDSC/OSG

100 Gbps FIONA at UCSC Allows for Downloads to the UCSC Hyades Cluster from the LBNL NERSC Supercomputer for DESI Science Analysis



INTERMEDIATE PALOMAR TRANSIENT FACTORY

300 images per night.
100MB per raw image

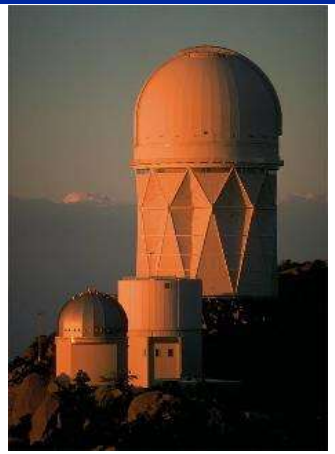
120GB per night

Source: Peter Nugent, LBNL
Professor of Astronomy, UC Berkeley

Precursors to LSST and NCSA



NSF-Funded Cyberengineer
Shaw Dong @UCSC
Receiving FIONA
Feb 7, 2017



Dark Energy Spectroscopic Instrument

250 images per night.
530MB per raw image

800GB per night

BERKELEY LAB
Bringing Science Solutions to the World

NERSC

PRP PACIFIC RESEARCH PLATFORM

NSF

CENIC

ESnet

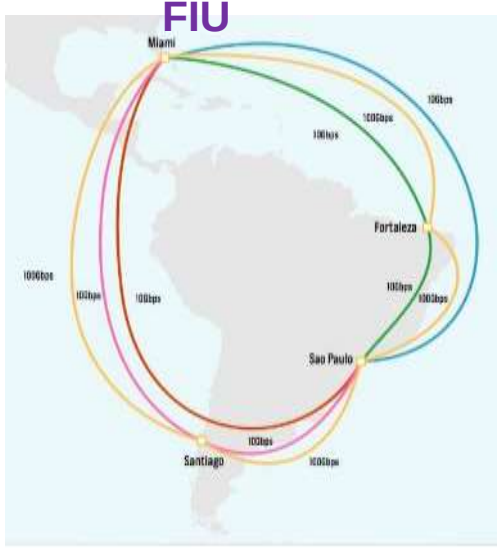
SDSC

CITRIS BANATAO INSTITUTE

it²

Global Scientific Instruments Will Produce Ultralarge Datasets Continuously Requiring Dedicated Optic Fiber, Supercomputers, and Machine Learning





NCSA will be the global central hub for the LSST processing, archiving, and serving the terabytes of data that will be collected every night of the decade-long survey

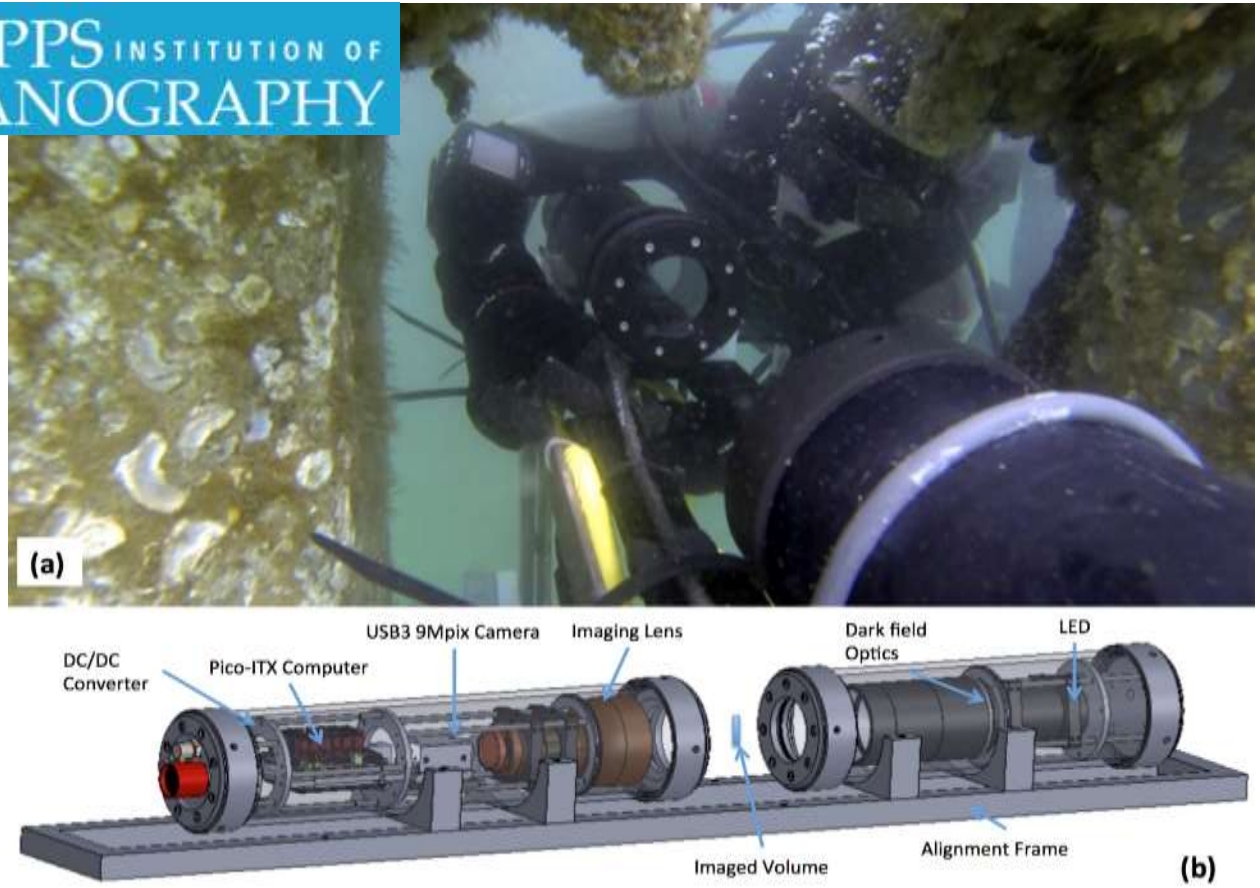
Use PRP-Like CI to Connect NCSA Repository To Remote Astronomy Big Data Analysis Users?

PRP PACIFIC RESEARCH PLATFORM

it²

UC San Diego Jaffe Lab (SIO) Scripps Plankton Camera Off the SIO Pier with Fiber Optic Network

SCRIPPS INSTITUTION OF OCEANOGRAPHY

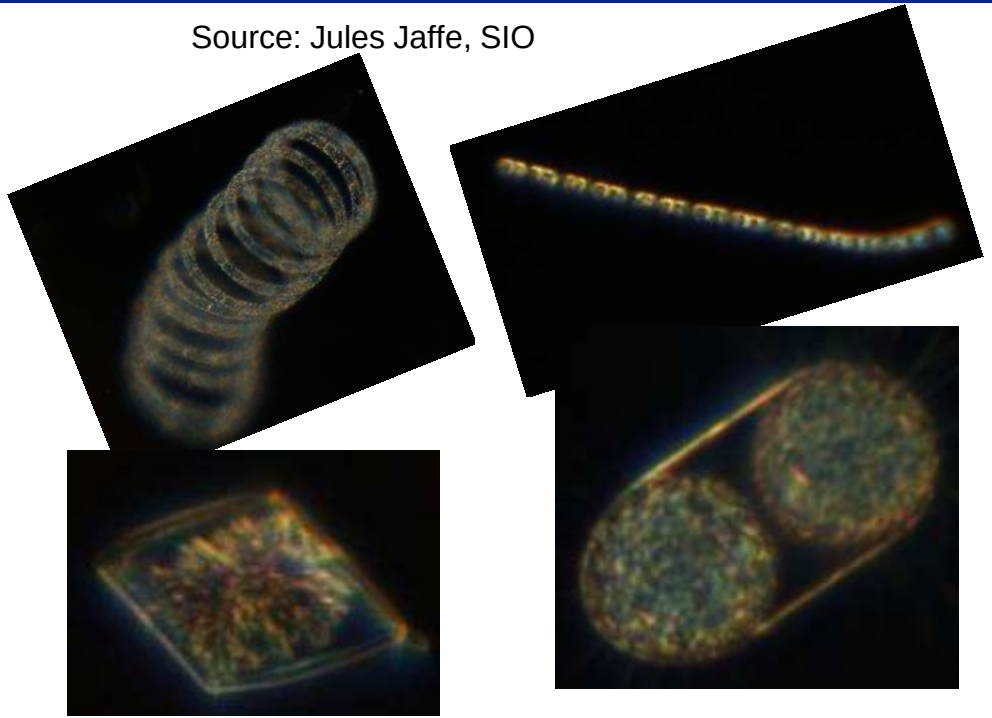


PRP PACIFIC RESEARCH PLATFORM

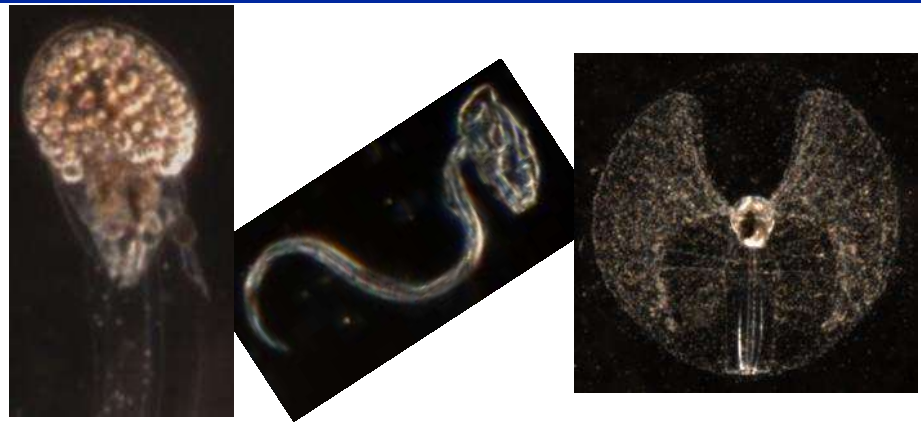
it²

Over 300 Million Images So Far!
Requires Machine Learning for Automated Image Analysis and Classification

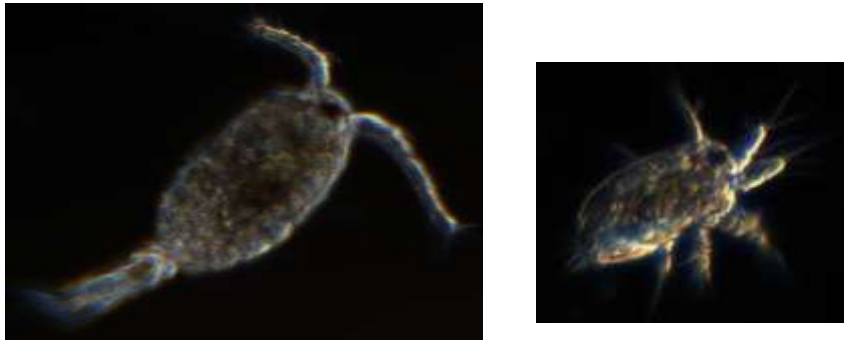
Source: Jules Jaffe, SIO



Phytoplankton: Diatoms



Zooplankton: Larvaceans



Zooplankton: Copepods

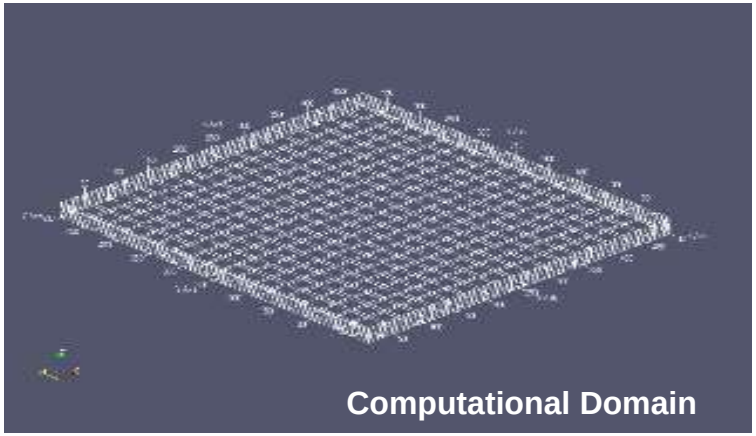
PACIFIC RESEARCH PLATFORM

”We are using the FIONAs for image processing... this includes doing Particle Tracking Velocimetry that is very computationally intense.”-Jules Jaffe

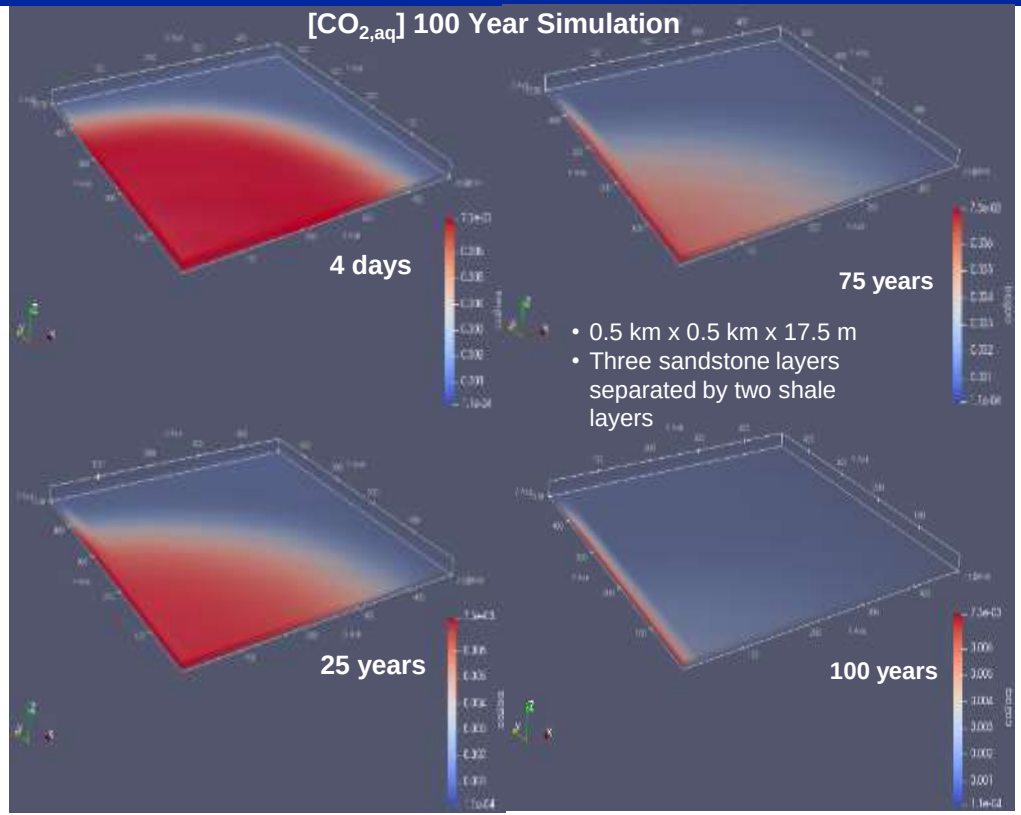
Moving a Supercomputer Application to a Distributed Computation on PRP:

Simulating the Injection of CO_2 in Brine-Saturated Reservoirs:

Poroelastic and Pressure-Velocity Fields Solved In Parallel Over the PRP, Using MPI for Domain Decomposition, Orchestrated by Kubernetes Containers on FIONA Nodes



Numerical methods:
Finite Elements for Solid Phase,
Finite Volume for Aqueous Phase



Evolution of Formation Water Carbonic Acid Concentration in Time, After 4 Days of Injection

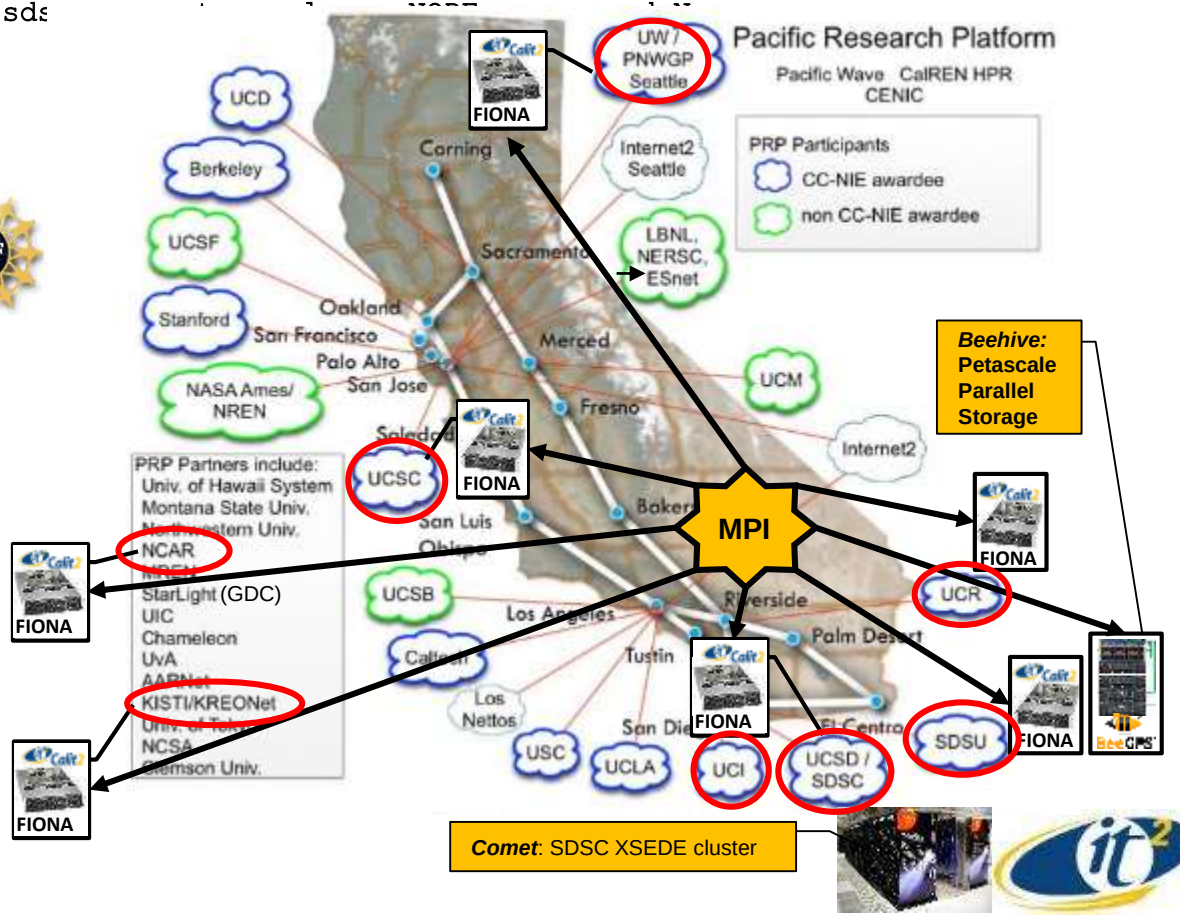
PRP Distributed-Parallel Computation: Using OpenMPI on Kubernetes to Create Distributed Pods

```
[paolini@fiona k8s]$ kubectl get pod -n sds
NODE
```

[Creating Kubernetes Distributed Pods]

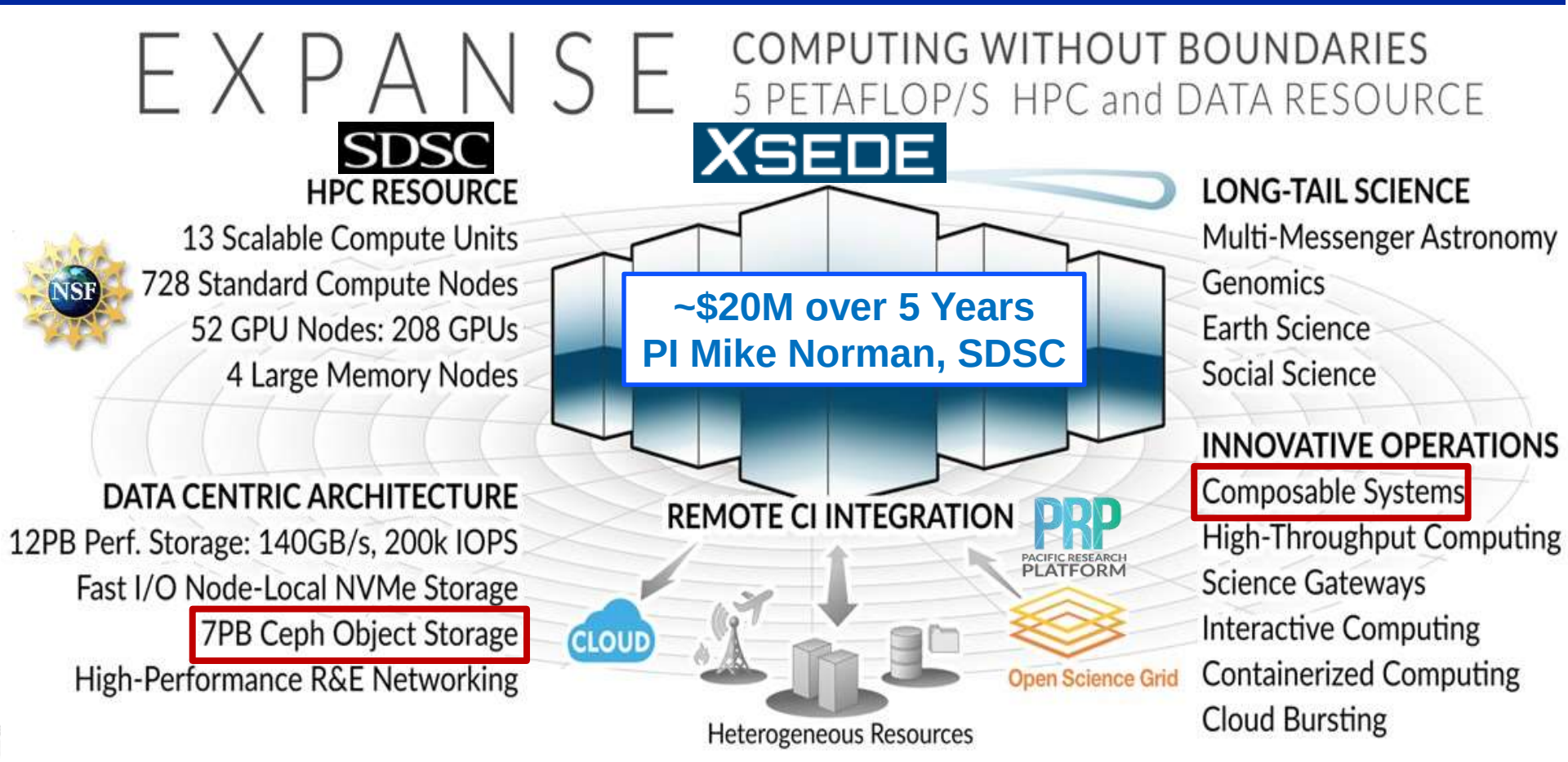
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dtn-main.ucr.edu
siderea.ucsc.edu
dtn2-daejeon.kreonet.net
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fiona.nwsc.ucar.edu
k8s-epyc-01.sdsc.optiputer.net
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Source: Chris Paolini, SDSU



PRP PACIFIC RESEARCH PLATFORM

2020-2025 NRP Future:
SDSC's EXPANSE Will Use CHASE-CI Developed Composable Systems



PRP/TNRP/CHASE-CI Support and Community:

- US National Science Foundation (NSF) awards to UCSD, NU, and SDSC
  - CNS-1456638, CNS-1730158, ACI-1540112, ACI-1541349, & OAC-1826967
  - OAC 1450871 (NU) and OAC-1659169 (SDSU)
- UC Office of the President, Calit2 and Calit2's UCSD Qualcomm Institute
- San Diego Supercomputer Center and UCSD's Research IT and Instructional IT
- Partner Campuses: UCB, UCSC, UCI, UCR, UCLA, USC, UCD, UCSB, SDSU, Caltech, NU, UWash UChicago, UIC, UHM, CSUSB, HPWREN, UMo, MSU, NYU, UNeb, UNC,UIUC, UTA/Texas Advanced Computing Center, FIU, KISTI, UVA, AIST
- CENIC, Pacific Wave/PNWGP, StarLight/MREN, The Quilt, Kinber, Great Plains Network, NYSERNet, LEARN, Open Science Grid, Internet2, DOE ESnet, NCAR/UCAR & Wyoming Supercomputing Center, AWS, Google, Microsoft, Cisco

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