



Software Defined Networking Program Review

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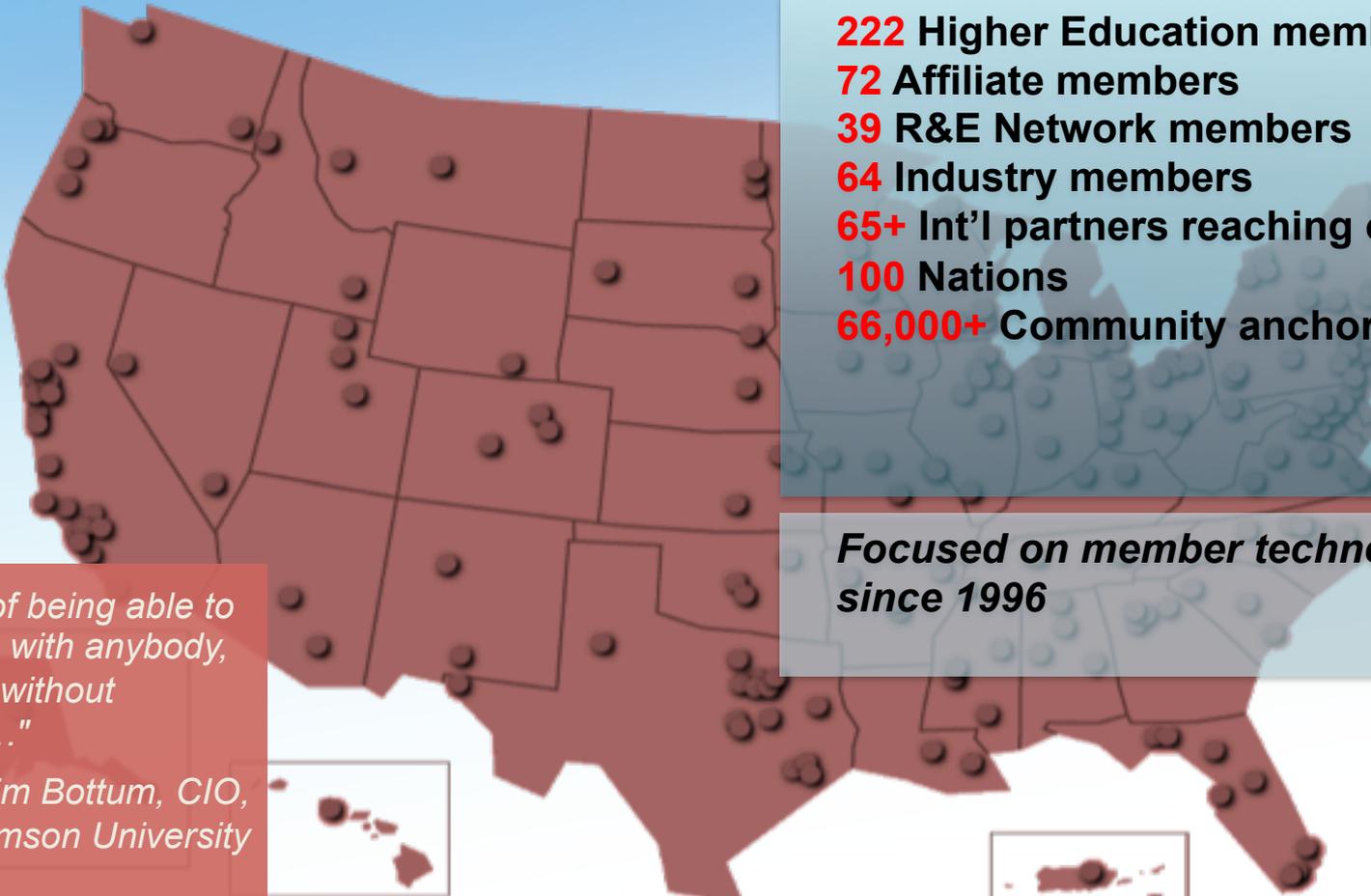
**INNOVATION IN ACADEMIA:  
*DEPLOYMENT, OPERATIONS, AND  
MANAGEMENT OF SOFTWARE-DEFINED  
NETWORKS***

# The Internet2 Community: An unparalleled human network



- Internet2 brings together thought leaders from member organizations and the broader research and education community
- Our community advances frontiers of network-enabled applications
- Our community accelerates innovation and enables transformation

# Internet2 Members and Partners



**222** Higher Education members  
**72** Affiliate members  
**39** R&E Network members  
**64** Industry members  
**65+** Int'l partners reaching over  
**100** Nations  
**66,000+** Community anchor institutions

*Focused on member technology needs since 1996*

*"The idea of being able to collaborate with anybody, anywhere, without constraint..."*

*—Jim Bottum, CIO,  
Clemson University*



*What will  
global innovators  
do with the next  
Innovation  
Platform?*

INTERNET®  
*2*

Creating new innovation opportunities

*begins with understanding*  
what enabled innovation in the past

- The research and education community played *a seminal role* in the creation of the modern Internet and the applications that have made it *the most transformative technology* of the last hundred years
- 34 of these leading universities created Internet2 in 1996



# R&E networking ROI has been staggering

Total 30-year federal investment to enable the precursors of the Internet is very small compared to the *businesses it spawned*

Earth 3963 mi

Venus

## These seminal investments

- Put the R&E community “way out in front” of commercial markets
- Created a new, bandwidth-rich playing field
- Enabled innovations that led to a *global transformation*: our information-based economy

ARPAnet, CSNET & NSFnet  
< \$250 million  
total investment

Cont  
eco  
of

Money, 2

*(Hamilton Consultants, 2009)*

INTERNET



Birth of major  
U.S. companies

Routers



CISCO™

Stanford

Search



Google™

Stanford

Security Systems



ARBOR®  
NETWORKS

Univ of Michigan

Computer Workstations



Sun  
microsystems

Berkeley, Stanford

Network Caching



Akamai

MIT

Security Systems



INTERNET  
SECURITY  
SYSTEMS™

Georgia Tech

Social Media



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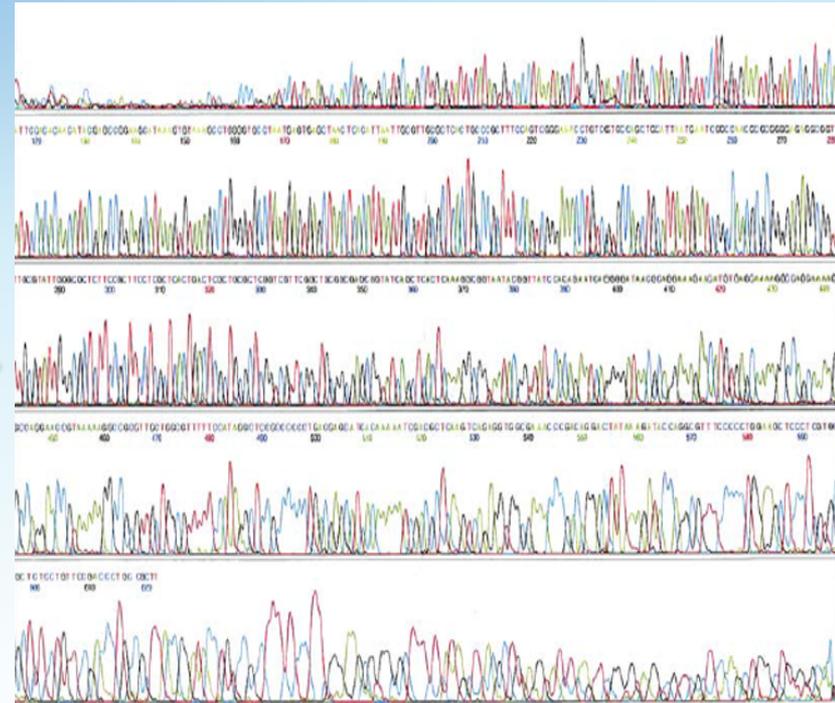
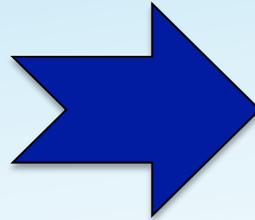
Harvard



*How do we create  
an at-scale  
Innovation Platform  
for the next era?*

# Innovation Use Case: Genomics Analysis

How do we bring petabytes of distributed data to and from compute resources and correlate gene sequences to accelerate cures for disease?



- Accelerated Bulk File Transfer of Massive File sets
- Content Distribution Caching / Distribution
- Clear Authorities & Health Security compliance
- High Performance Compute, Storage, Visualization

## *Innovation Platform vision:*

# Abundant bandwidth

### Innovation roadblock



- Limited capacity a major barrier—*need more than incremental boosts*
- Too expensive and risky to try totally new approaches
- Closed approaches limit applications or use cases

### Innovation route



- Raw capacity now available on Internet2 Network a key imagination enabler
- Incent disruptive use of new, advanced capabilities
- Promote “open” and creative freedom of use

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*Innovation Platform vision:*

# Software-defined networking (SDN)

## Innovation roadblock



- Proprietary software in routers and switches
- Communications with hardware limited by actual, physical, proprietary components
- Application developers have to use the network as prescribed

## Innovation route



- Open up network layer to innovation
- Let innovators communicate with and program *the network itself*
- Allow developers to optimize the network for specific apps



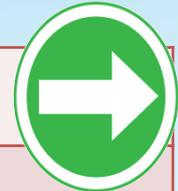
# Support for data-intensive science

## Innovation roadblock



- One-size-fits-all approach to network data flows
- Lack of transparent performance monitoring solution
- No way to customize and optimize the network via SDN

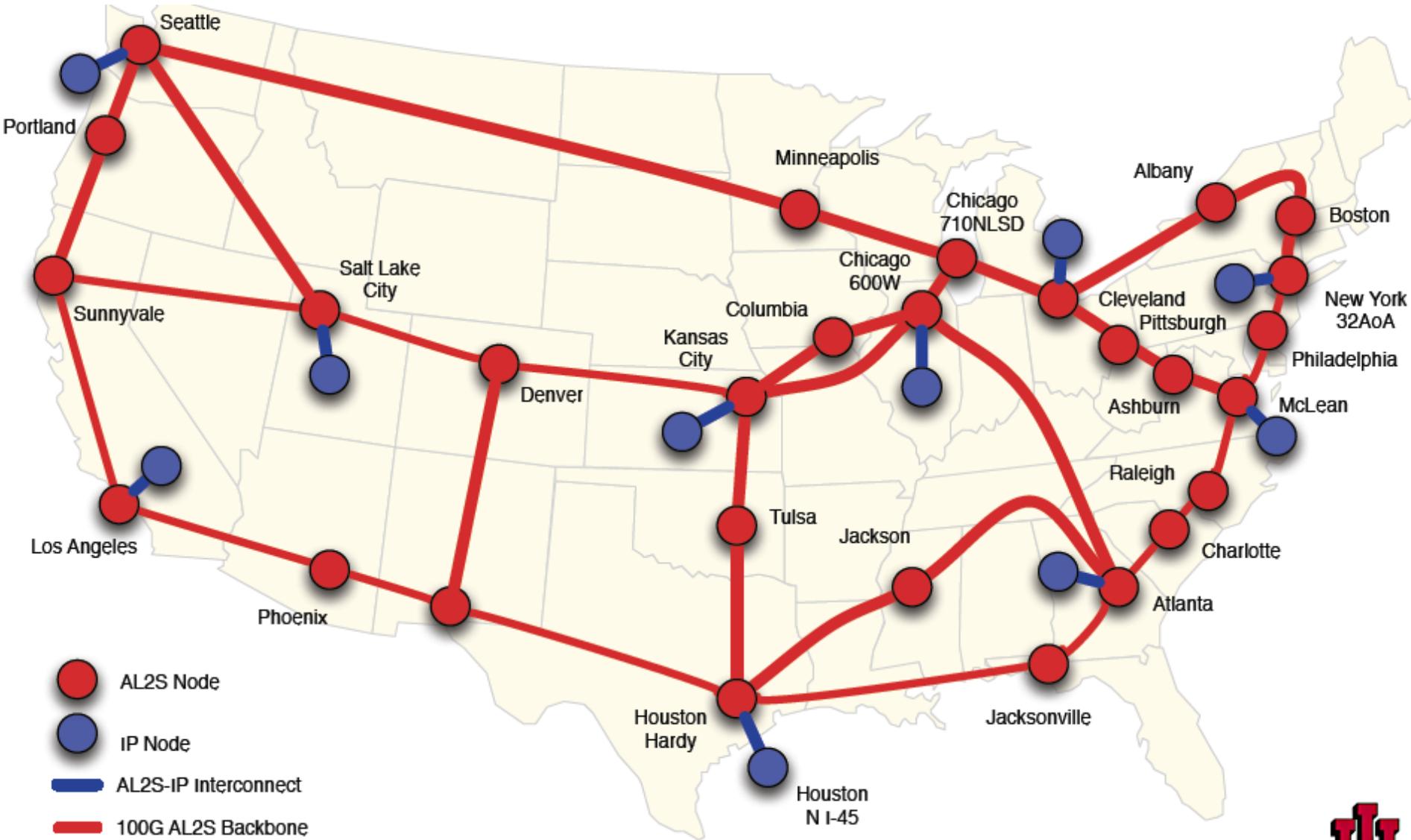
## Innovation route



- Architect a special solution to allow higher-performance data flows
- Include end-to-end performance monitoring
- Include SDN server to support programmability

# Internet2 Advanced Layer 2 Service

- Underpins national SDN testbed and innovation platform program
- 100G capability for data intensive science



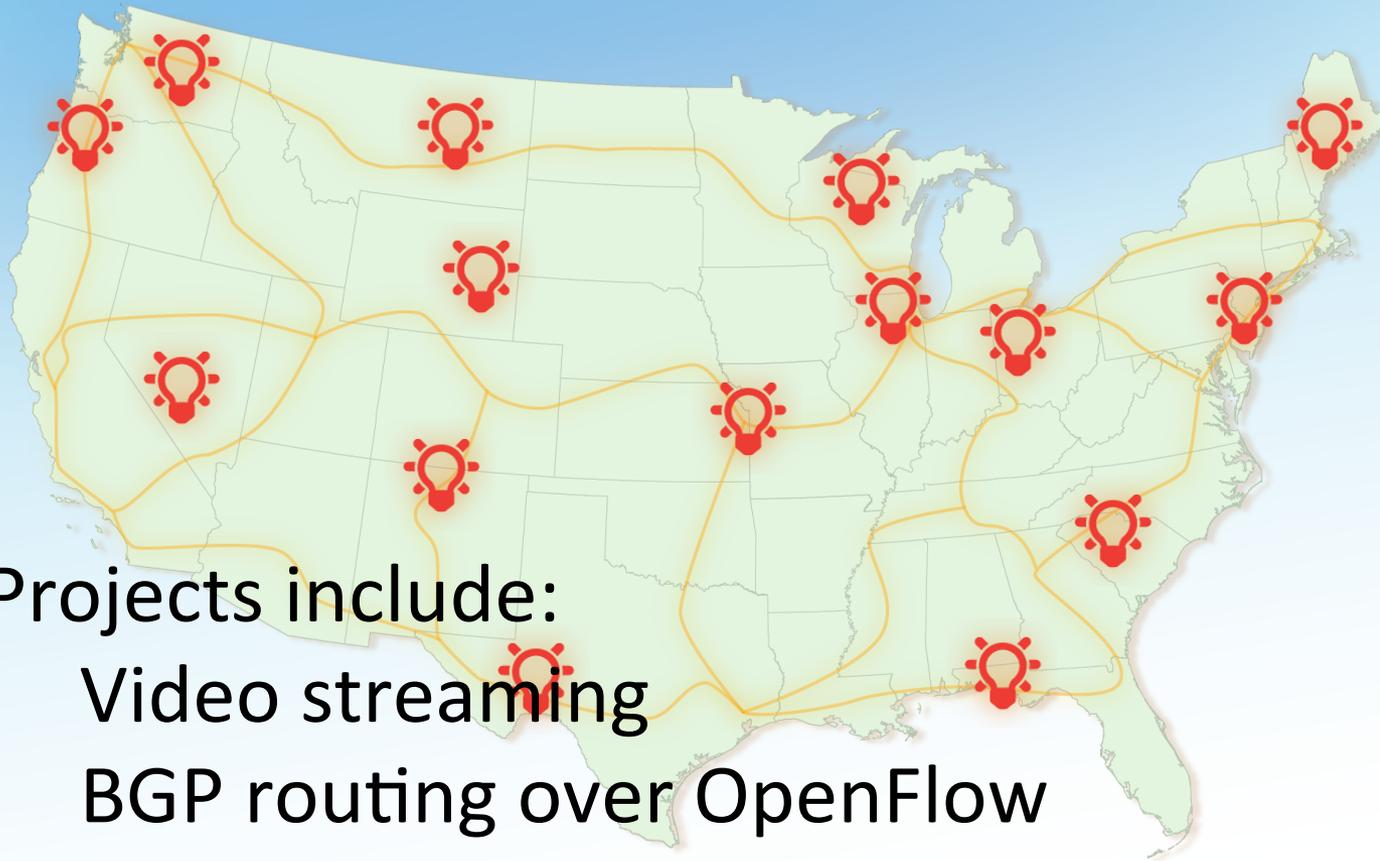


# Innovation Campus Pilot Sites

100GE – Science DMZ – Software-Defined Networking



# 2013 Internet2 Innovative Application Awards



Projects include:

Video streaming

BGP routing over OpenFlow

SDN for Exchange Points

GENI integration

**GOLD**

**JUNIPER**  
NETWORKS

**SILVER**

**ciena**

**BRONZE**

**BROCADE** 

# Overview

- Creating a Climate for Innovation
- **R&E Deployment**
- Operations and Management

# Innovation

## Campus Matrix

Significant progress on implementing the 3 platform components:

- 19 100 GE
- 16 Science DMZ
- 18 SDN

Campus	100 GE	Science DMZ	SDN Support
Arizona State University		X	X
California Institute of Technology	X	X	X
Case Western Reserve University	X		
Clemson University	X	X	X
Drexel University			
Georgia Institute of Technology			
Indiana University	X	X	X
Johns Hopkins University	X		
National Library of Medicine	X		
Stanford University		X	X
The Ohio State University	X		
Texas A&M University		X	X
US Naval Research Laboratory	X		
University of Arizona			
University of California Davis	X	X	X
University of California Los Angeles	X	X	X
University of California San Diego		X	X
University of California Santa Cruz	X	X	X
University of Chicago			
University of Cincinnati	X		
University of Florida	X	X	X
University of Illinois Urbana-Champaign	X	X	X
University of Iowa		X	X
University of Maryland	X	X	X
University of Michigan			
University of Missouri		X	X
University of Oklahoma	X		
University of Southern California	X	X	X
University of Virginia	X		
University of Wisconsin	X	X	X
Virginia Tech	X	X	X



# Innovation Pilot Regionals

Supporting Regional Network	100 GE	Science DMZ	SDN Support	# of Campuses with CC-NIE
CIC OmniPoP	X			
Florida LambdaRail/Southern Crossroads (FLR/SOX)	X			4
OARnet	X			4
OneNet	X			1
Mid-Atlantic Research Infrastructure Alliance (MARIA)	X		X	2
CENIC	X	X	X	9
Indiana GigaPOP	X	X	X	2
Mid-Atlantic Crossroads (MAX)	X	X	X	2
Three Rivers Optical Exchange/Drexel	X	X	X	2
<b>Totals</b>	<b>8</b>	<b>4</b>	<b>5</b>	<b>26</b>

# Innovation Campuses

Campus	100 GE	Science DMZ	SDN Support	Campus	100 GE	Science DMZ	SDN Support
University of Arizona				National Library of Medicine	X		
Arizona State University		X	X	US Naval Research Laboratory	X		
Stanford University		X	X	University of Maryland	X	X	X
University of California San Diego		X	X	University of Michigan			
California Institute of Technology	X	X	X	University of Missouri Case Western Reserve University	X		
University of California Davis	X	X	X	The Ohio State University	X		
University of California Los Angeles	X	X	X	University of Cincinnati	X		
University of California Santa Cruz	X	X	X	University of Oklahoma	X		
University of Southern California	X	X	X	Drexel University			
University of Florida	X	X	X	Clemson University	X	X	X
Georgia Institute of Technology			X	Texas A&M University		X	X
University of Iowa		X	X	University of Virginia	X		
University of Chicago				Virginia Tech			X
University of Illinois Urbana- Champaign	X	X	X	University of Wisconsin	X	X	X
Indiana University	X	X	X	<b>Totals</b>	<b>19</b>	<b>16</b>	<b>18</b>
Johns Hopkins University	X						

# NSF CC-NIE Infrastructure Awardees

Auburn University  
California Institute of Technology  
Case Western Reserve University  
Colorado State University  
Dartmouth College  
Duke University  
Florida International University  
Florida International University  
Florida State University  
Georgetown University  
Johns Hopkins University  
Kansas State University  
Lehigh University  
Louisiana State University & Agricultural and Mechanical College  
North Carolina State University  
Northwestern University  
Oregon State University  
Pennsylvania State Univ University Park  
San Diego State University Foundation  
Stephen F. Austin State University  
Syracuse University  
Texas A&M University Corpus Christi  
Texas A&M University Main Campus  
Tulane University  
University of California-Berkeley  
University of California-Irvine  
University of California-San Diego  
University of California-San Diego  
University of California-Santa Cruz  
University of Central Florida  
University of Colorado at Boulder  
University of Connecticut  
University of Connecticut Health Center  
University of Dayton  
University of Florida  
University of Hawaii System  
University of Idaho  
University of Illinois at Urbana-Champaign  
University of Michigan Ann Arbor  
University of Nebraska-Lincoln  
University of New Hampshire  
University of North Carolina at Chapel Hill  
University of Notre Dame  
University of Oregon Eugene  
University of Pennsylvania  
University of Puerto Rico-Rio Piedras  
University of Southern California  
University of Tennessee Knoxville  
University of Washington  
University of Wisconsin-Madison  
Virginia Polytechnic Institute and State University  
Virginia Polytechnic Institute and State University  
Wayne State University  
Wittenberg University  
Yale University

# NSF CC-NIE Integration Awardees

California Institute of Technology  
Carnegie-Mellon University  
Clemson University  
Colorado State University  
Duke University  
Indiana University  
Indiana University  
Louisiana State University & Agricultural and Mechanical College  
Ohio State University  
Pennsylvania State Univ University Park  
Stanford University  
University of California-Davis  
University of Chicago  
University of Houston  
University of Kentucky Research Foundation  
University of Maryland College Park  
University of Maryland College Park  
University of Massachusetts Amherst  
University of Missouri-Columbia  
University of Montana  
University of Nebraska-Lincoln  
University of North Carolina at Chapel Hill  
University of Oklahoma Norman Campus  
University of Southern California  
University of Tennessee Knoxville  
University of Tennessee Knoxville  
University of Utah  
University of Virginia Main Campus  
Vanderbilt University

# Progress to Date – Pilot Campuses

- 100 GE
  - Campuses have implemented it in the campus, WAN or both
  - Outstanding issues for campuses without 100 GE
    - Waiting for equipment or connection to be installed
    - Still in the budgeting process
- Science DMZ
  - Many campuses with existing Science DMZ plan to expand it to
    - include additional connections, or
    - integrate SDN into the Science DMZ environment
- SDN
  - SDN implementations support research, production or both
  - SDN capable equipment include a mixture of OpenFlow and DYNES based implementations

# Progress to Date – Pilot Campuses

- 11 Sites have implemented all 3 components
  - Majority plan to expand on the existing components
  - Many research projects specifically depend on one or more platform component
- 22 of the 31 pilot sites received NSF CC-NIE grants
  - 9 of the 11 sites that implemented all 3
- perfSONAR
  - Most, if not all, sites plan to deploy perfSONAR platforms as part of their Science DMZ
  - Innovation Pilot campus perfSONAR mesh is planned as part of the program

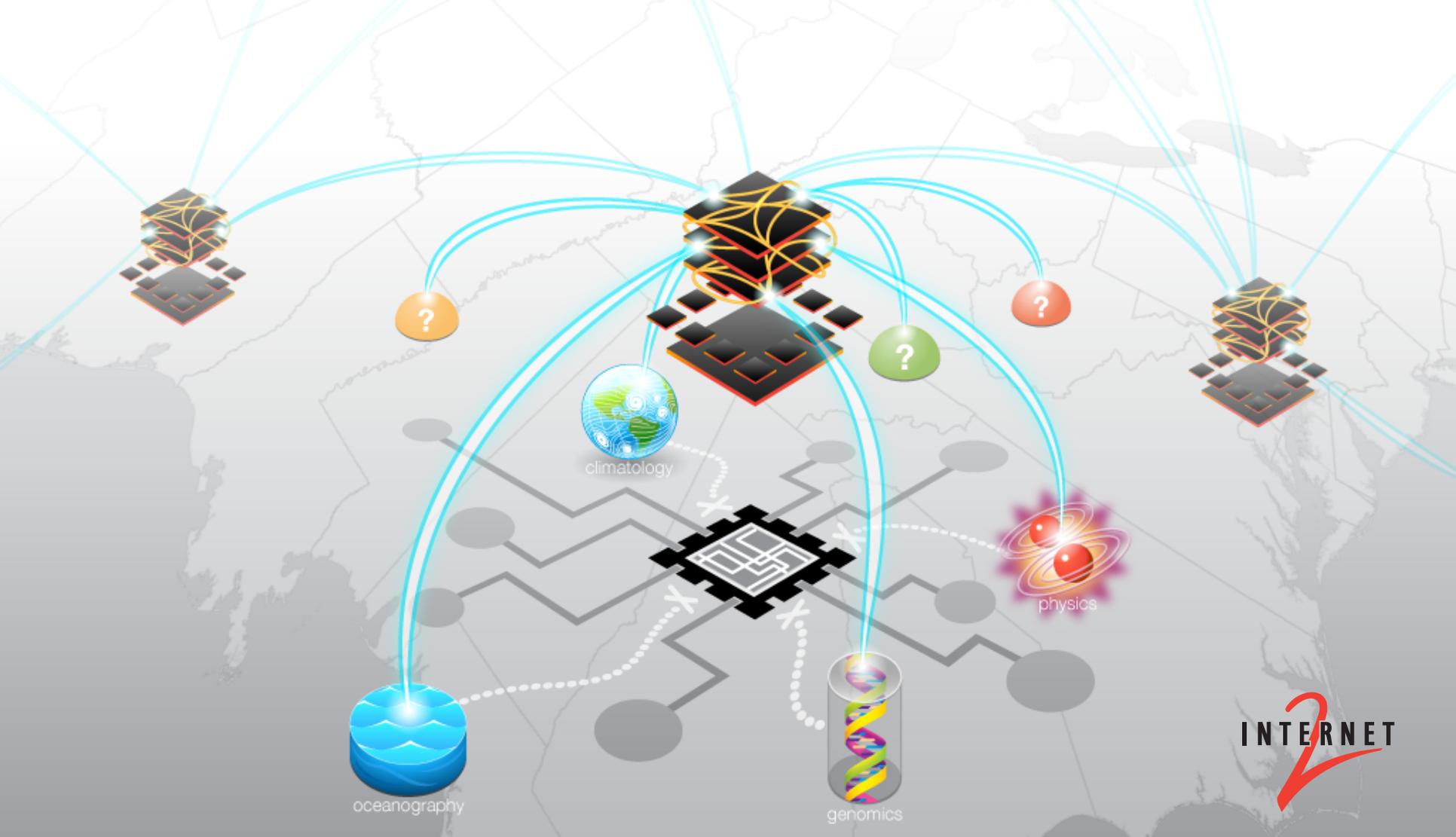
# Progress to Date – Regional R&E Networks

- 9 Regional R&E Networks participating in the program
  - All R&E networks have implemented 100 GE – either regional infrastructure, connection to Internet2 or both
  - 4 have science DMZ's, including not having any equipment that limits bandwidth for R&E traffic
  - 5 have software defined networking infrastructure for research, production or both
- All Regional R&E Network pilots have at least one campus who received a CC-NIE grant
  - Regionals themselves are not eligible
  - Collectively support a total of 26 campuses with CC-NIE grants
    - Not all are Innovation Pilot Campuses

# Advanced Layer2 Service Deployment



This is what we have been able to say for about a year:  
The **100G** testbed of innovation for tomorrow's Internet is available  
nationwide, right now.



Does this create a platform for innovation?

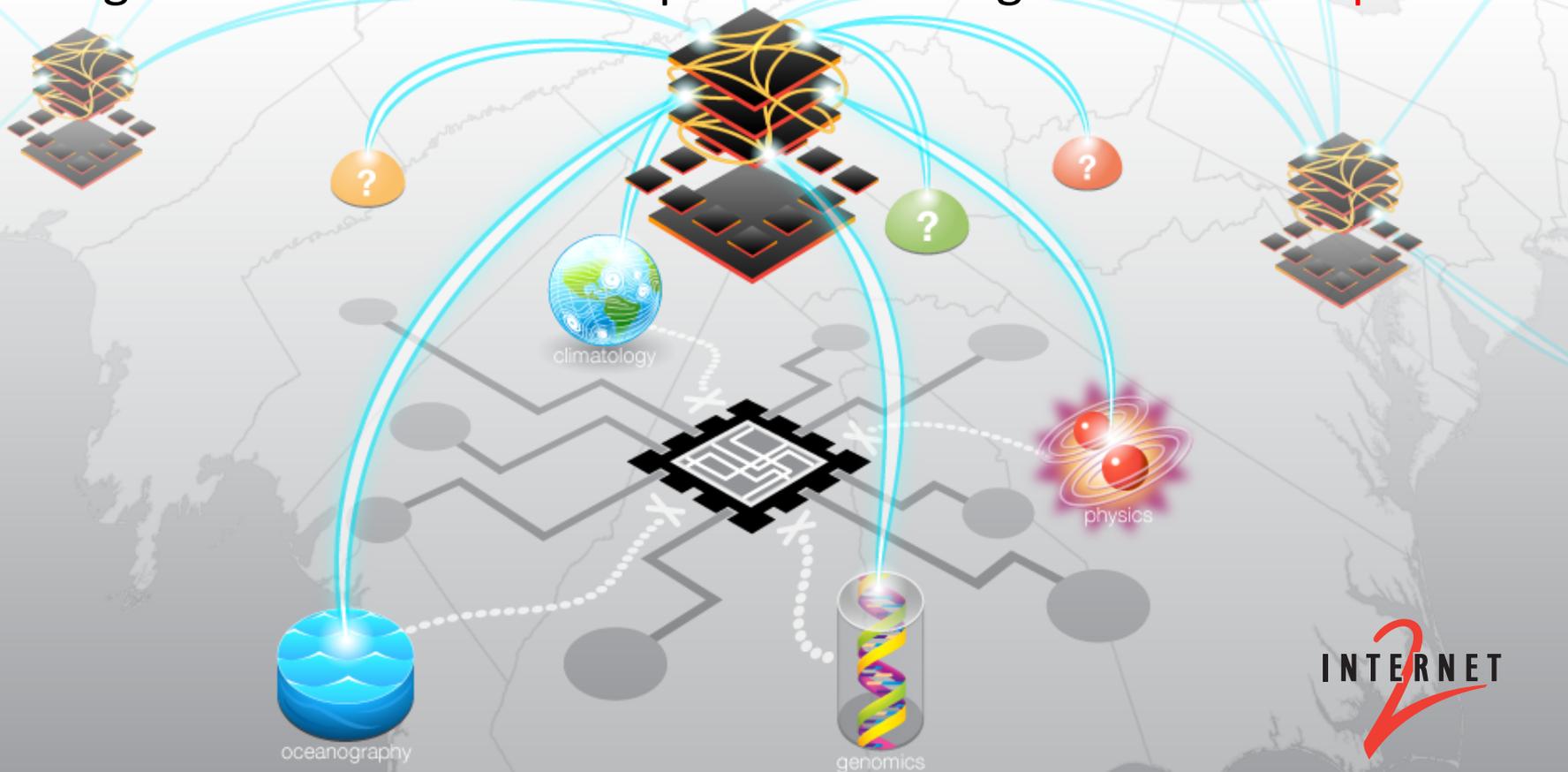
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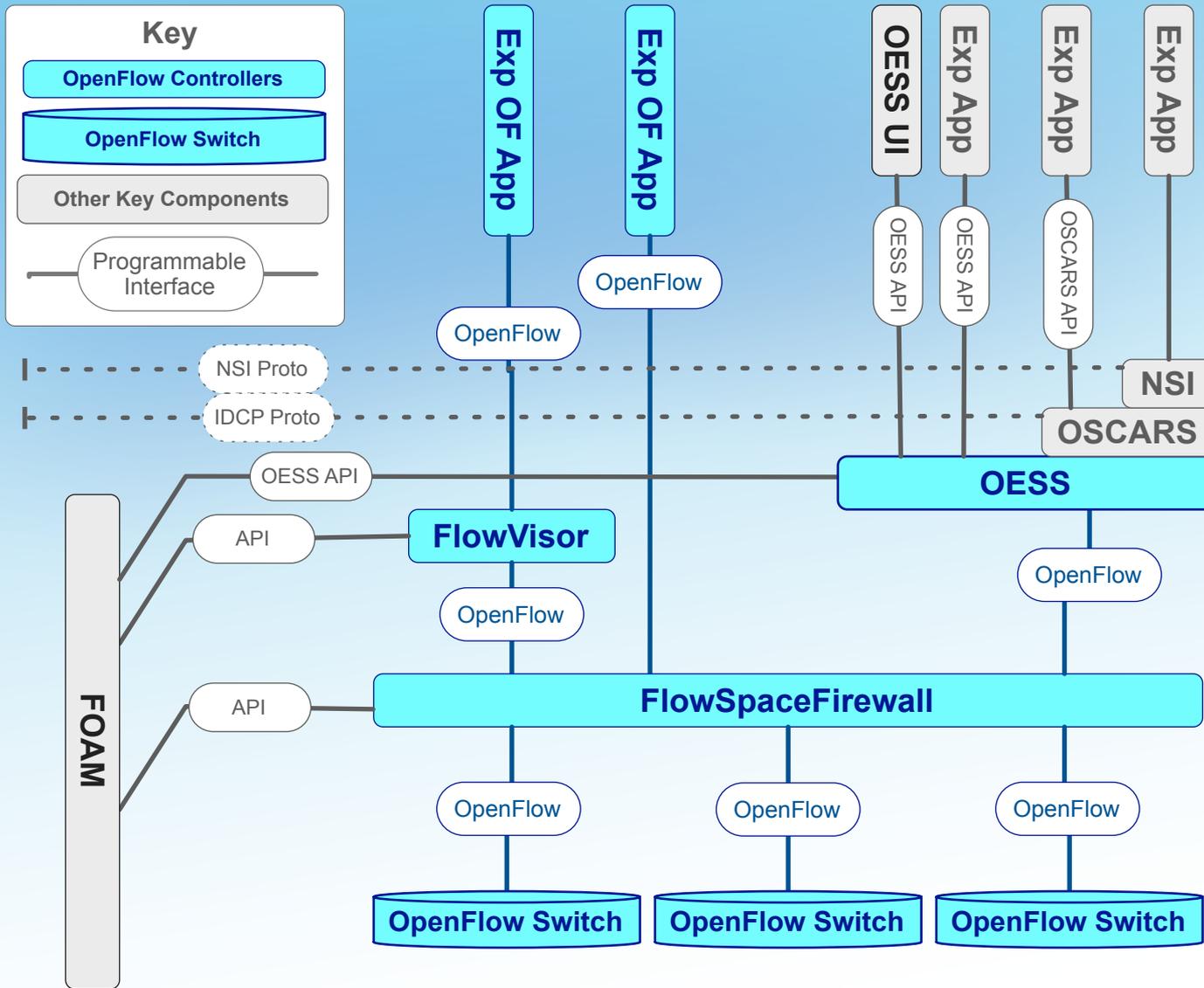
Software-defined networking substrate?

Support data intensive science?

Virtualization?  In progress

Integrate network with compute and storage?  Next step





AL2S Software Stack

Q1 Late 2014?



# Operations by the Numbers

- Availability
  - 99.97 including Scheduled Maintenance
  - 99.989 not including Scheduled Maintenance
  - Outages not SDN-related
- Utilization
  - 100G, 40% “headroom” threshold
  - Current trend: 40%+ utilization by July 2014 on several circuits
- Circuit Provisioning
  - 2000+ circuit events in the last 4 month period
  - Half interdomain requests (i.e. OSCARS) and half direct requests (i.e. OESS)

# INTERNET<sup>2</sup>

- 100G Nationwide Backbone
- Native OpenFlow w/ virtual slices
- Multivendor Environment
- Available at Public Peering Points
- Full Year of solid production experience
  
- Open for controlled experimentation

Provides production & innovation platform to:

- Dozens of high performance compute clusters
- Hundreds of campus data centers
- Thousands of native OpenFlow ports
- Hundreds of wireless access networks
- Millions of potential collaborators



*What will  
global innovators  
do with the next  
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DEFINED NETWORKS***

**Rob Vietzke, Internet2**

Vice President, Network Services

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Thank you. For more information,  
visit <http://www.internet2.edu>  
or e-mail [innovation@internet2.edu](mailto:innovation@internet2.edu)

# An observation

**1.5 Mb – 100 Mb**

*innovation accelerates  
R&E out in front*

# about our past

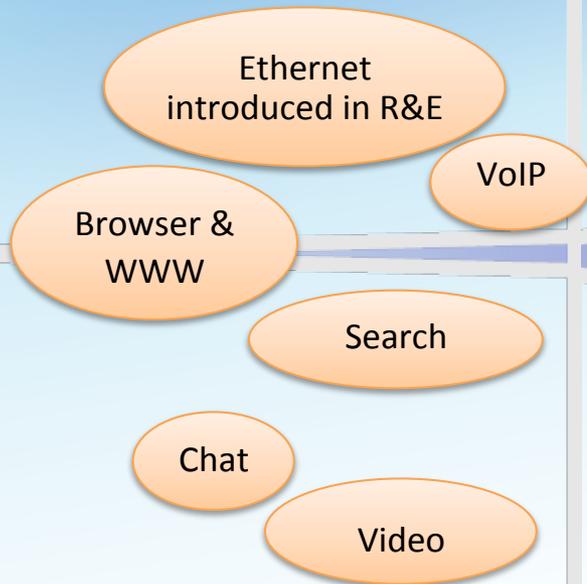
**100 Mb – 10 Gb**

*innovation slows  
R&E leadership fades*

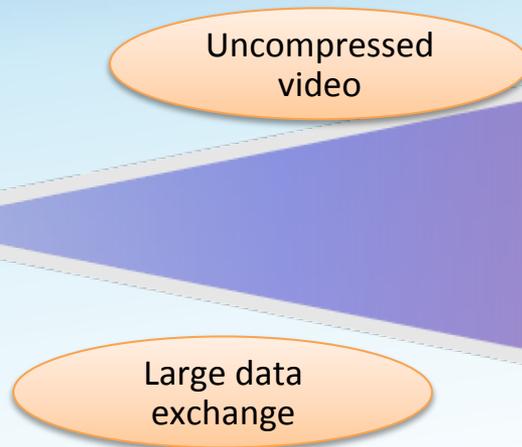
# and the future

**10 Gb – 1Tb Gb**

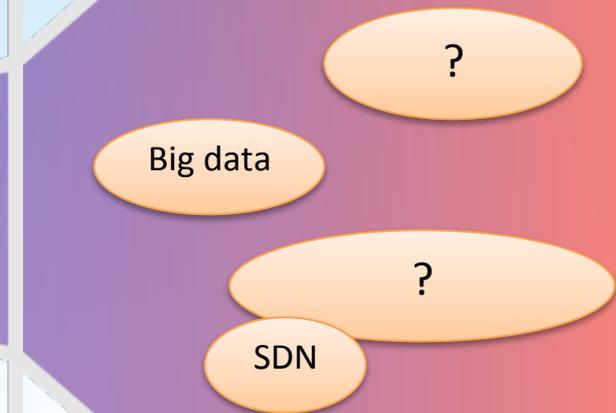
*innovation opportunity  
where is R&E?*



*Theme in this era is investment and positioning for the future*



*Theme in this era becomes aggregation, cost savings, efficiency, competition*



*What will the theme of this era be?*

INTERNET

# Program Goal

Development of next generation, open source applications that are of general interest to the research and education community and take advantage of SDN-enabled capabilities that improve data movement across 100G OpenFlow-enabled networks such as the Internet2 Advanced Layer2 Service

# Contest Timeline

- May 2013 – Program Announcement
- June 7, 2013 - Proposals Due
- June 25, 2013 – Proposal Notification
- July 1 - Oct 4, 2013 – Application Development
- October 15, 2013 – Submission of Application
- November 2013 – Application Demonstrations
- December 2013 – Applications available online

# Program Summary

- Aimed at undergraduate and graduate students at US based colleges and universities
- \$10,000 cash award
  - \$2,000 for when the proposal is accepted
  - \$8,000 for submission of completed, working project
  - Individual not institutional awards

# Selected Projects

- 8 proposals selected for completion
- Project teams
  - Individuals as well as teams
  - Graduate, undergraduate and university staff
  - Most projects had a faculty or staff advisor
- Project types
  - Data movement, network management software, security

# Current Status

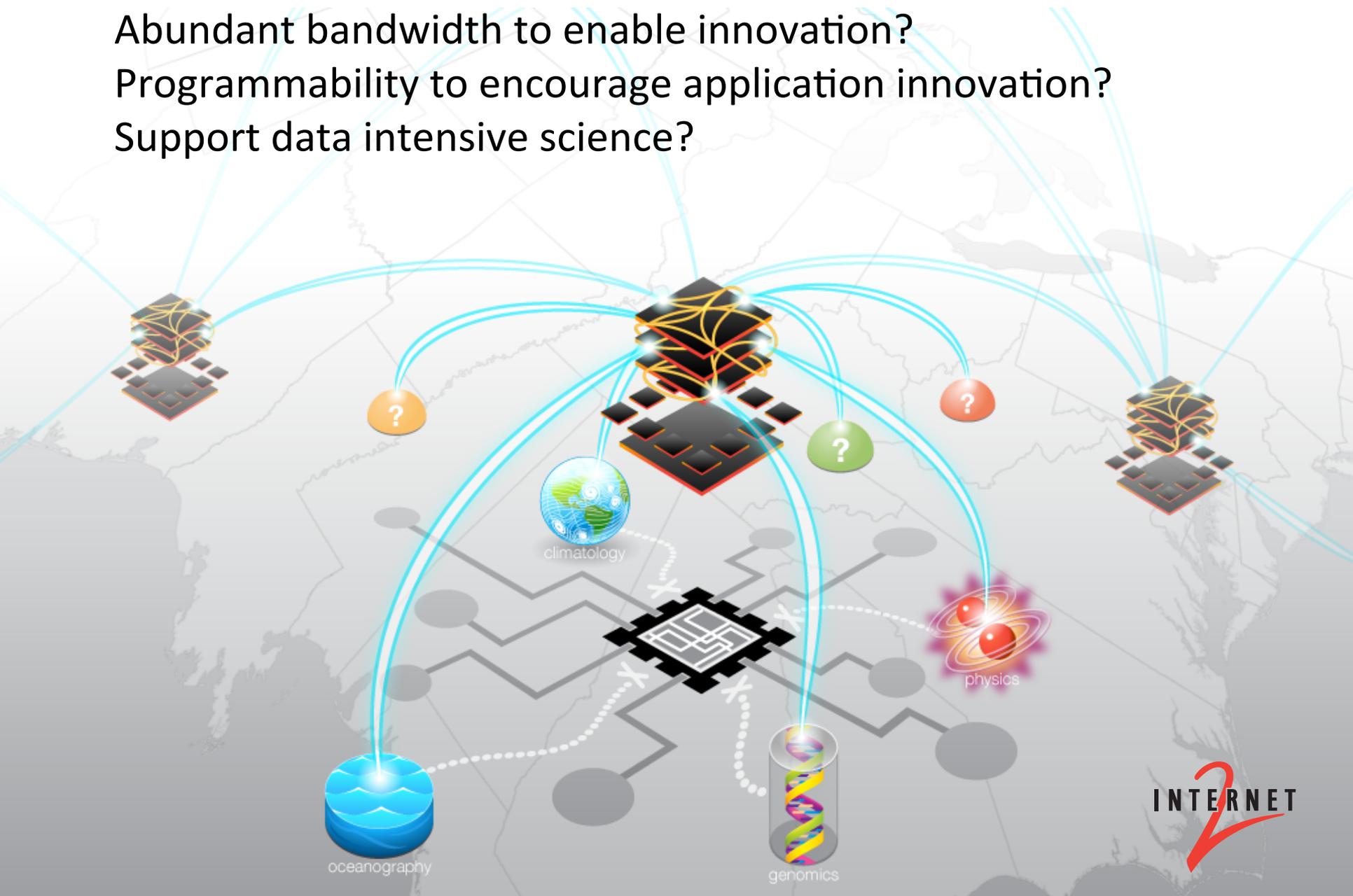
- Projects completed
  - Source code available from a public code repository
  - Documentation
    - Code documentation
    - Final report
    - Slide presentation
- Application demonstrations
  - November 2013

# Does this create a platform for innovation?

Abundant bandwidth to enable innovation?

Programmability to encourage application innovation?

Support data intensive science?

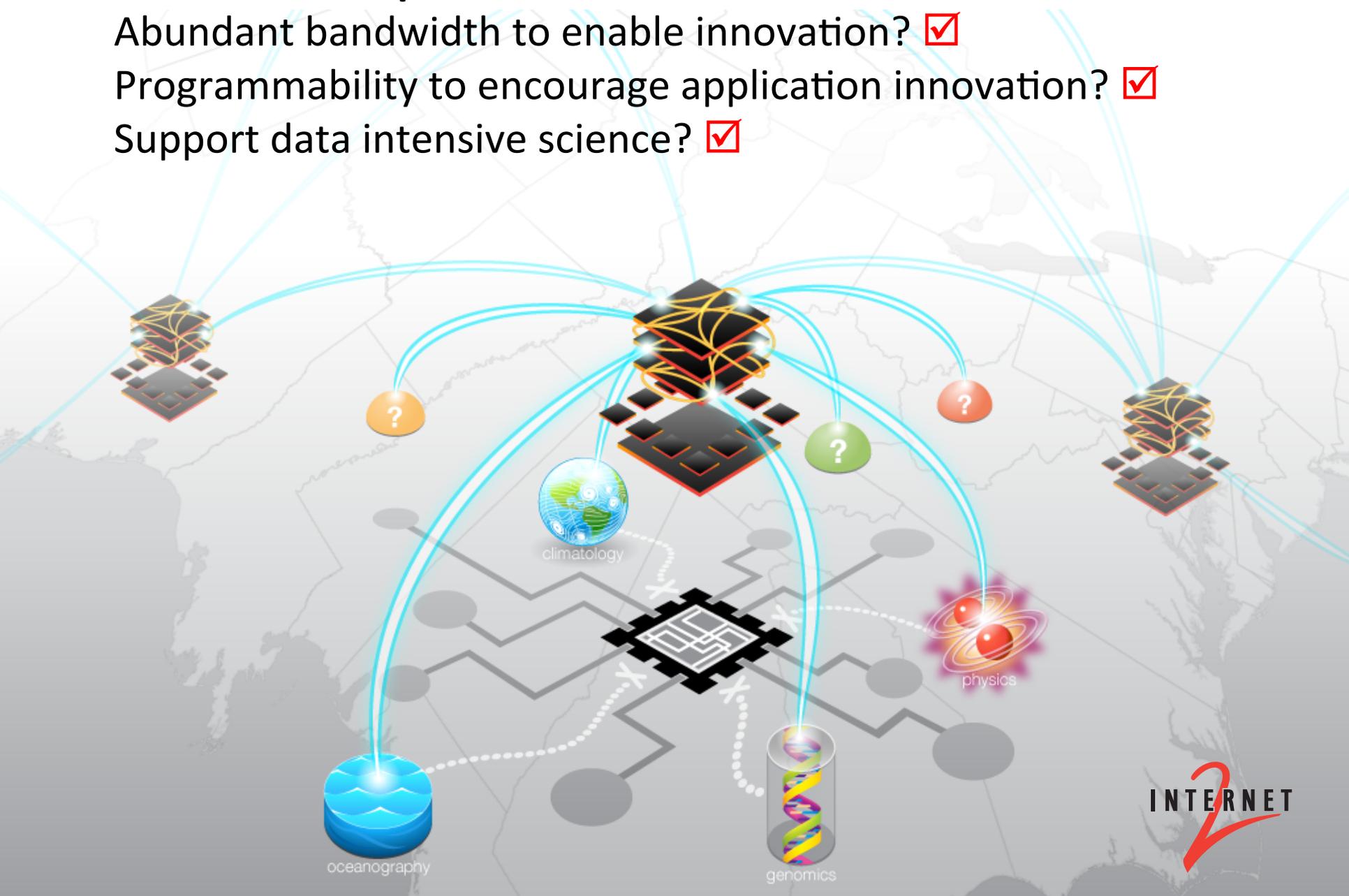


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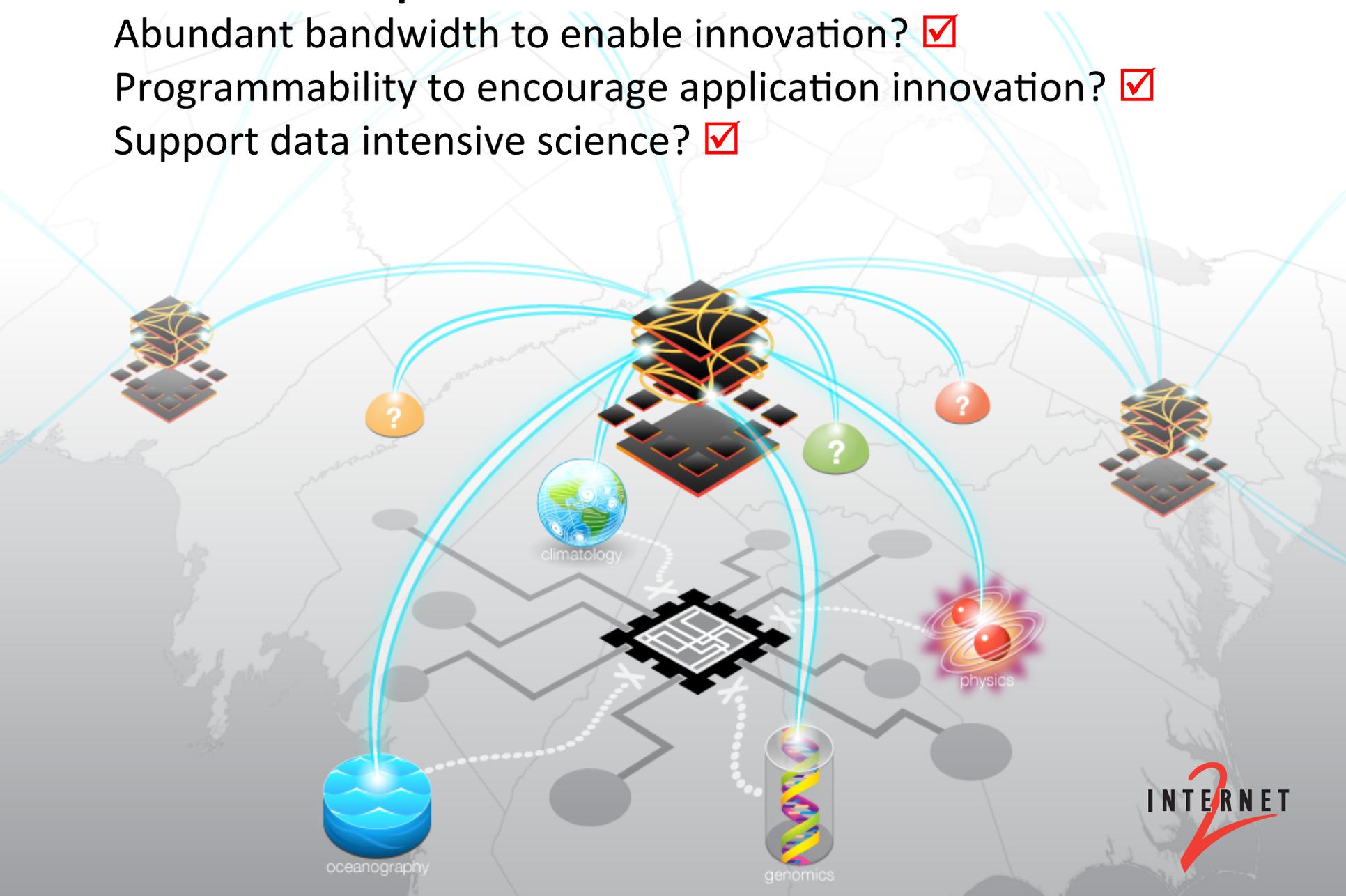
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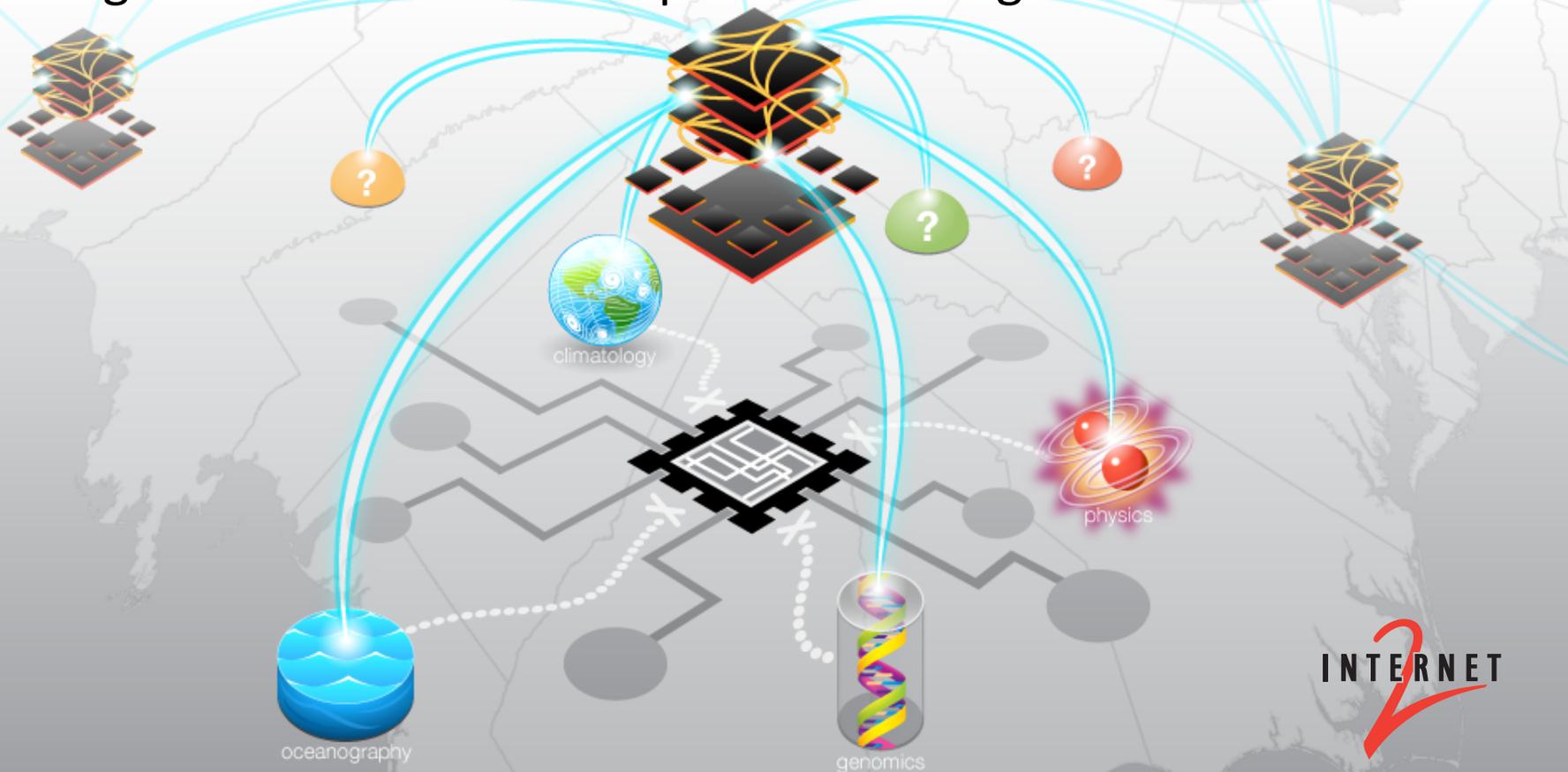
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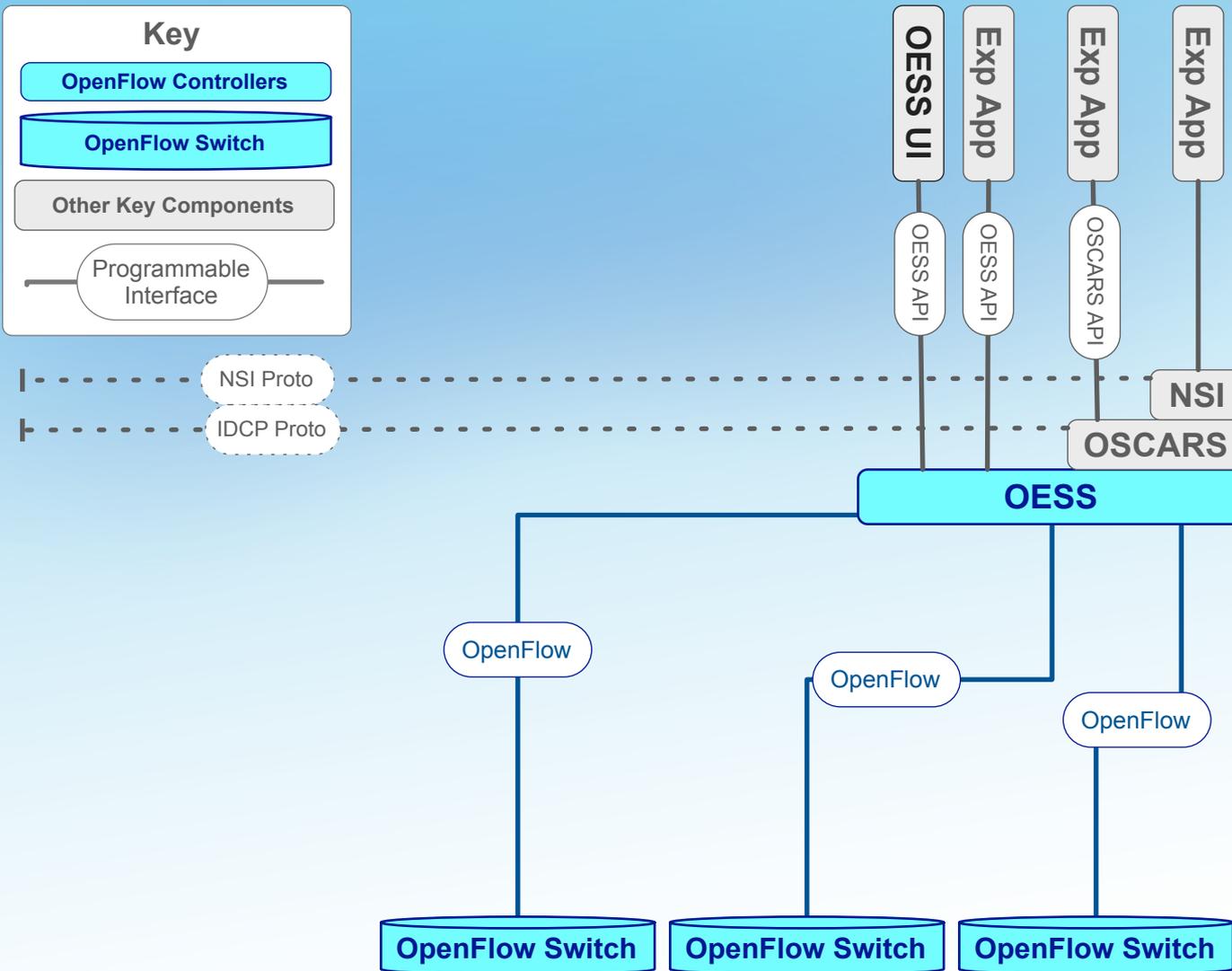
Software-defined networking substrate?

Support data intensive science?

Virtualization?

Integrate network with compute and storage?





AL2S Software Stack

GEC17 Configuration



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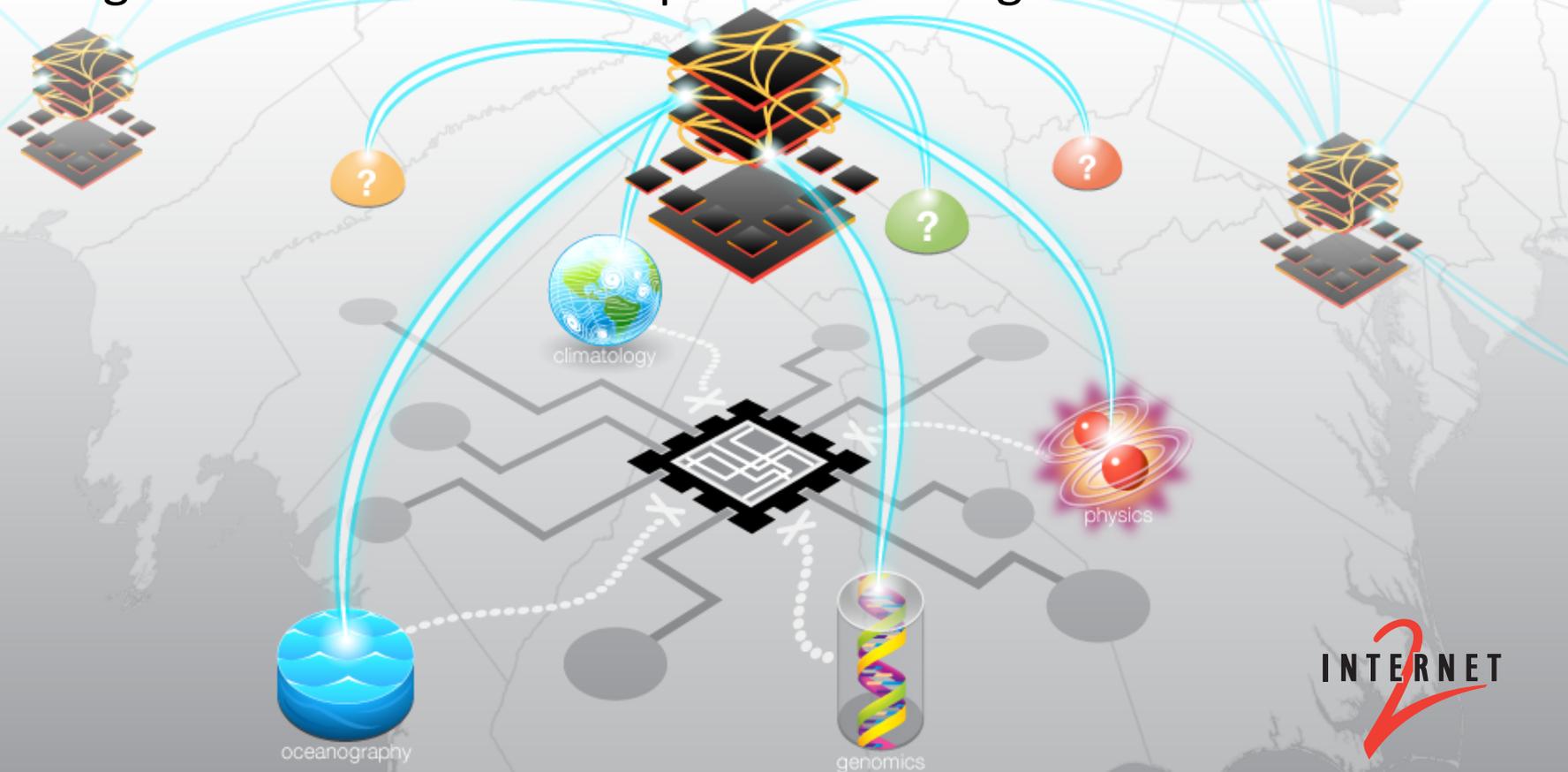
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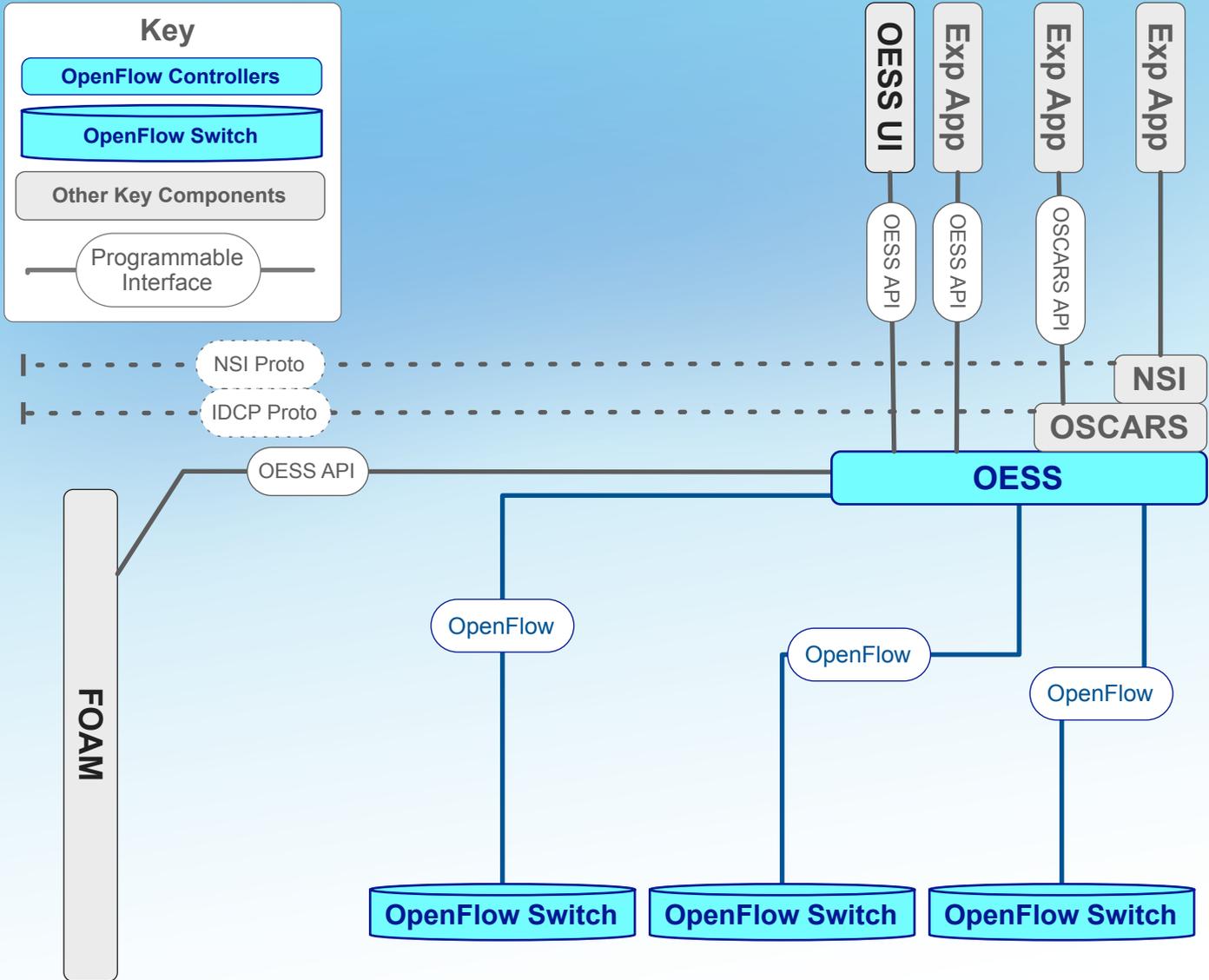
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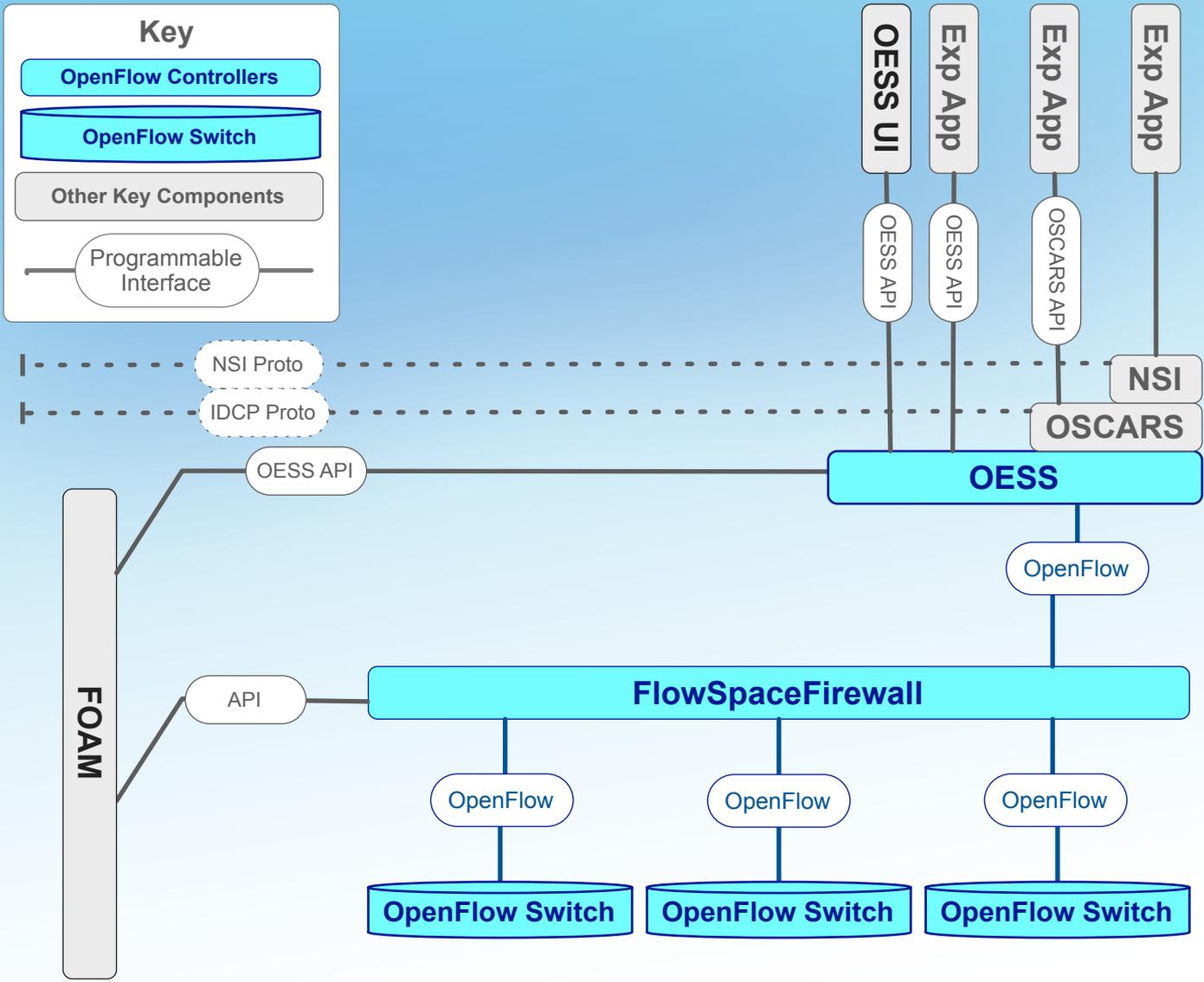




AL2S Software Stack

GEC18 Configuration





AL2S Software Stack

Late Q4 2013?





# Network virtualization

## Innovation roadblock



- One-size-fits-all approach to network architecture
- Support for legacy networking protocols
- Production concerns outweigh network research needs

## Innovation route



- Multiple network architectures through virtualized networks
- Run new networks in parallel with legacy networks
- Isolate virtual networks on a common physical network

## *Innovation Platform vision:*

# Integration of Compute and Storage

### Innovation roadblock



- Network is distinct from compute and storage
- Compute and storage on the periphery of the network
- Applications cannot observe and control network

### Innovation route



- Integrate compute, storage, and network into a distributed computation platform
- Compute and storage available in the middle of the network
- Application observes and controls entire platform

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